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# A PROTOTYPE MICROPROCESSOR BASED AUDIOMETER FOR USE BY THE CF MEDICAL SERVICES FOR PERIODIC HEARING TESTS

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# ABSTRACT

This report describes a prototype microcomputer-based audiometer designed to demonstrate the potential of such technology for routine periodic hearing testing in the Canadian Forces (CF). Besides the microcomputer and its dual-disk drive, display screen and printer, the system is comprised of an interface box containing a crystal clock, frequency synthesizer, digital attenuator, electronic switch, audio amplifier, acoustic earphone calibrators, and patient-response interface circuitry. The threshold-detection paradigms are based on the modified Hughson and Westlake procedure. The associated software provides prompts to the technician for parameters and data for each patient (e.g., age, social insurance number (SIN), military occupation code (MOC), along with prompts during the testing if problems are encountered. After a test is completed, the patient's CF hearing category is computed and displayed on the screen audiogram form, and the test results are stored automatically in a disk file for future reference.

## INTRODUCTION

The Canadian Forces (CF) hearing conservation program is intended to control the harmful effects of high intensity noise, thereby promoting operational effectiveness and conserving manpower resources. Hearing loss due to noise exposure tends to increase most rapidly during the early years of exposure(1). Since such losses do not generally become apparent until damage to the inner ear is well established, the identification of the onset and growth of hearing loss in individuals who are overly susceptible and/or overexposured to noise is an important element in the program(2).

In practice, the CF program has not been entirely successful in this respect. The onset and growth of hearing loss can be observed by recording the hearing threshold levels of individuals upon enlistment, and by monitoring their thresholds periodically throughout their careers. For a number of reasons (e.g., training and operational priorities, limited resources), many non-flying noise-exposed personnel have not received periodic hearing tests, at least until the age of 40 when annual physical examinations become mandatory for everyone in the CF.

Moreover, the usefulness of the data is limited by the fact that hearing tests conducted at base-hospital MIRs are subject to inconsistencies in the test procedures. Also, the medium on which test results are stored (i.e., hand-completed audiogram forms) precludes the efficient transfer of all the test data from an individual's audiogram (rather than a single-number hearing category such as H1, H2, H3, H4) into a central data-base for epidemiological study and assessment of the program(3).

With the advent of large-scale military and industrial hearing-test programs, it became evident that procedural errors in manual hearing testing had to be controlled(4), and a means devised of centralizing and analyzing the data efficiently. A first effort in this direction was the development in 1955 of a self-recording audiometer using a discrete-frequency Békésy tracking procedure(5). Shortly thereafter, a computer-assisted audiometer was developed to support the USAF hearing conservation program(6). However, the technology was not developed sufficiently at the time to make the device practical.

In the early 1970s, programs were being developed to demonstrate the efficiency of mini-computers in controlling pure-tone and speech audiometric procedures(7,8,9). With the emergence of microprocessor technology, a first-generation microprocessor audiometer was built for the USAF which could control signal-detection paradigms, provide inconsistent-response detection algorithms, and store data automatically on media to facilitate information storage, transfer and analysis(10). A number of commercial microprocessor-controlled audiometers possessing some of these capabilities were available by the late 1970s(11).

In 1982, the Director of Preventive Medicine for the CF Medical Services concluded that the application of microprocessor technology to the periodic-audiometry program could enhance the effectiveness of the hearing conservation program. As a result, DCIEM was tasked to investigate the applicability of computer controlled audiometry in the CF and study means of its implementation (12). A system was needed whereby hearing tests would be controlled by software which prompts the technician from a microcomputer screen for parameters and data for each patient (e.g., age, social insurance number (SIN), military occupation code (MOC), along with prompts during the testing if problems are encountered. After a test is completed, the patient's CF hearing category would be computed and displayed on the screen audiogram form, and the data would be stored automatically in a disk file for future reference. The technician could obtain on the computer display screen any of the patient's previous hearing tests that are filed on one of the system's discs. The results of previous hearing tests not filed on the floppy disc but available from the patient's medical file could be entered into the system from the microcomputer terminal.

A survey indicated that current off-the-shelf microprocessor-based audiometers did not meet fully the above requirements. Accordingly, it was decided to develop under contract, to DCIEM specifications, a prototype CF system. The contract was awarded to Sound Linked Data Inc., Mississauga Ontario, who subcontracted the hardware fabrication to Garrow Laboratories. This report is intended to outline the design features and operating characteristics of the prototype system.

## PROTOTYPE DESIGN AND OPERATION

The prototype system is controlled by a Commodore CBM 8032 or 8296 microcomputer, including a CBM 8050 dual-disk drive and an Epson FX-80 dot-matrix printer. (A subsequent system was modified to operate with an IBM-compatible PC using the RS-232C interface bus.) The microcomputer is connected through a IEEE-488 interface bus to a Programmed Audiometric Threshold Detector box (PATD-01M) which contains a crystal clock, frequency synthesizer, digital attenuator, electronic switch, audio amplifier, acoustic earphone calibrators, and patient-response interface circuitry. A block diagram of the system is shown in Figure 1, the PATD-01 interface box in Figure 2, and the earphone acoustic-calibration system in Figures 3 and 4. The acoustic specification for the system is given in Table I. The operation of the system is given in detail in Appendix C.

TABLE I

MICROPROCESSOR-CONTROLLED AUDIOMETER: ACOUSTIC SPECIFICATION

| | |
|---|---|
| Hearing Level Range | -10 to 90 dB (250 to 8000 Hz)<br>-10 to 70 dB (125 Hz) |
| Signal Increments | 5 dB |
| Signal Amplitude Accuracy | ± 1 dB |
| Signal Duration | Random from 1 to 2 seconds in Continuous or Pulsed Mode |
| Between-Signal Interval | Random from 1 to 3 seconds |
| Patient Response Interval | From the Start of the Tone Presentation to 3 seconds beyond the Tone Presentation |
| Frequency Range | 125, 250, 500, 1000, 2000, 3000, 4000, 6000, 8000 Hz |
| Frequency Accuracy | ± 0.1% |
| Total Harmonic Distortion | Less than 0.5% |
| Signal-to-Noise Ratio | 60 dB |
| Signal Rise Time | 60 msec ± 15% |
| Signal Decay Time | 30 msec ± 15% |

## THRESHOLD DETECTION PROCEDURE

Presently accepted clinical-test procedures for establishing auditory thresholds are based on the technique of Hughson and Westlake[13] (method of limits) and the modifications suggested by Carhart and Jerger[14]. That is, auditory stimuli are presented to an observer in ascending hearing-level (HL) increments until a response occurs, thereupon the intensity is decreased and a new ascending series is begun. Each stimulus presentation occurs for a discrete period during an unmarked observation interval during which the listener responds if the stimulus is detected.

The search strategy for determining a threshold is to decrease the signal level by 10 dB following a positive response to a signal presentation, and to increase the signal by 5 dB following the absence of a response. Threshold is defined as the lowest HL at which responses occur in at least one-half of a series of HL ascending trials with a minimum of either three responses out of four required at a single level (defined herein as *75 per cent threshold detection)*, or two responses out of four (defined as *50 per cent threshold detection)*. Typical HL test sequences are given in Appendix A for a variety of patient responses, based on the default start-level of 40 dB HL.

In this procedure, the observer's detection criterion is highly subject to attentional and bias effects. On the other hand, typical laboratory procedures such as the adaptive two-interval forced-choice (2IFC) method minimize criterion effects. The procedure is generally more time consuming, but can be expected to yield lower thresholds with relatively better test-retest reliability [15].

Lack of measurement precision may be due as much to physical factors, however, as to the threshold-detection paradigm. Changes in the standing waves beneath the earphones, and hence the sound pressures impinging on the patient's eardrum, result from differences in earphone positioning [16]. Further, the task of listening for pure-tone signals at or near threshold may be affected by the noise of an individual's breathing and heartbeat, or by distracting or masking noise in test areas that are not ideal (see Appendix D). Consequently, the modified Hughson and Westlake procedure is the basis for the threshold-detection paradigms used in the prototype system (see Appendix B).

## SYSTEM ASSESSMENT AND DISCUSSION

An informal user-assessment of the microprocessor audiometer was carried out by technicians of the DCIEM Central Medical Board. The universal criticism was that hearing tests required more time to complete using the microprocessor-controlled system than with a manual screening audiometer, particularly when the 75 per cent threshold-detection criterion was used. Anecdotal evidence suggests that technicians are able to complete a manual six-frequency binaural test in less than four minutes, at least with attentive normal-hearing patients.

As a result, a pilot study was conducted to assess the effect of detection criterion on the precision of measured thresholds, as manifest by repeat-test variability, and on the trade-off between precision and time required to complete a test (see Appendix E). The findings suggest that a threshold criterion based on three (rather than two) responses at a given intensity level does not reduce replication variability. Moreover, in so doing the time required by patients to complete a test increases by from about one-half to four minutes, depending the hearing level of the patient and whether the test is completed without program interrupts due to inconsistent responses.

It should be noted that the subjects employed in the study were intended to represent a typical cross section of the CF population. That is, they had little or no experienced in near-threshold signal tracking and detection, and were not accustomed to attending continuously to such a task for periods often in excess of six to eight minutes. The relatively large number of inconsistent responses observed in the study may, therefore, be representative of what could be expected in Base Hospital MIRs where periodic screening audiometry will be conducted. It would appear, then, that the use of too rigorous a threshold detection criterion, with the accompanying increase in testing time, is inappropriate.

A second user evaluation was initiated at the MIR, CFB Downsview. A microprocessor system was installed and connected to the hearing test booth, and a system demonstration and instructions were given to the technicians responsible for hearing testing. The system remained at the MIR for approximately six months, and during that time received little or no use. It was realized subsequently that the technicians concerned had no interest in, or experience with microcomputers, and suggested that the introduction of this technology into the operations of the CF Medical Service will require formal introductory training.

## CONCLUSIONS AND RECOMMENDATIONS

As noted in the introduction to this report, DCIEM was tasked to investigate the applicability of computer controlled audiometry to the CF hearing conservation program and study means of its implementation.

Certainly, this technology makes it possible to standardize hearing-test paradigms throughout the CF, and store threshold results in a form that facilitates their recall or transfer to a central data base. Moreover, microprocessors can be programmed to detect inconsistencies in response, indicative of pathologies such as tinnitus, of patients who do not understand or are unable to perform the required automatic tracking and detection task, or of individuals attempting to falsify their audiometric record.

It would appear, however, that the use of too rigorous threshold- or fault-detection criteria, with the accompanying increase in testing time, is inappropriate for general CF use. In the prototype system described herein, for example, the 50 per cent threshold detection criterion should be employed for routine periodic hearing testing.

Before this type of audiometric equipment can be introduced into all CF hearing-test sites, such sites must be equipped with test rooms that meet the necessary CSA ambient-noise requirements.

Otherwise, intermittent noise may mask the test tones that a patient is attempting to detect, resulting in inconsistent responses, and causing undue test-program interrupts.

As with the introduction of any new technology, it will be necessary to provide training to personnel in order that they become familiar with, and gain confidence in microprocessor-controlled hearing testing.

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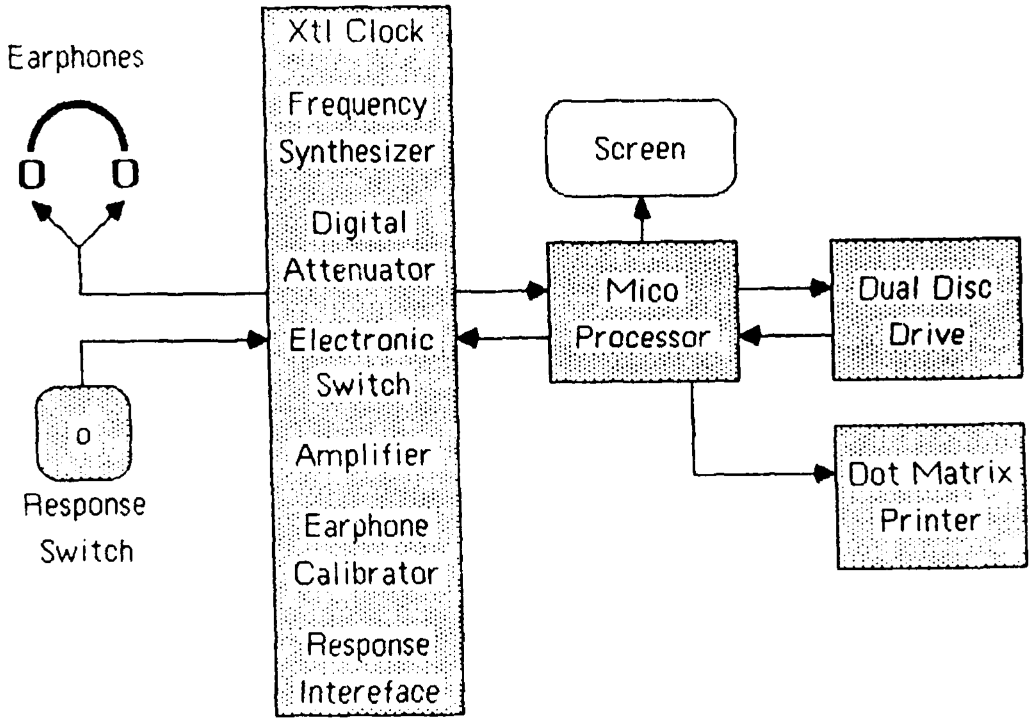



FIGURE 1. Block diagram of the microprocessor controlled audiometer.

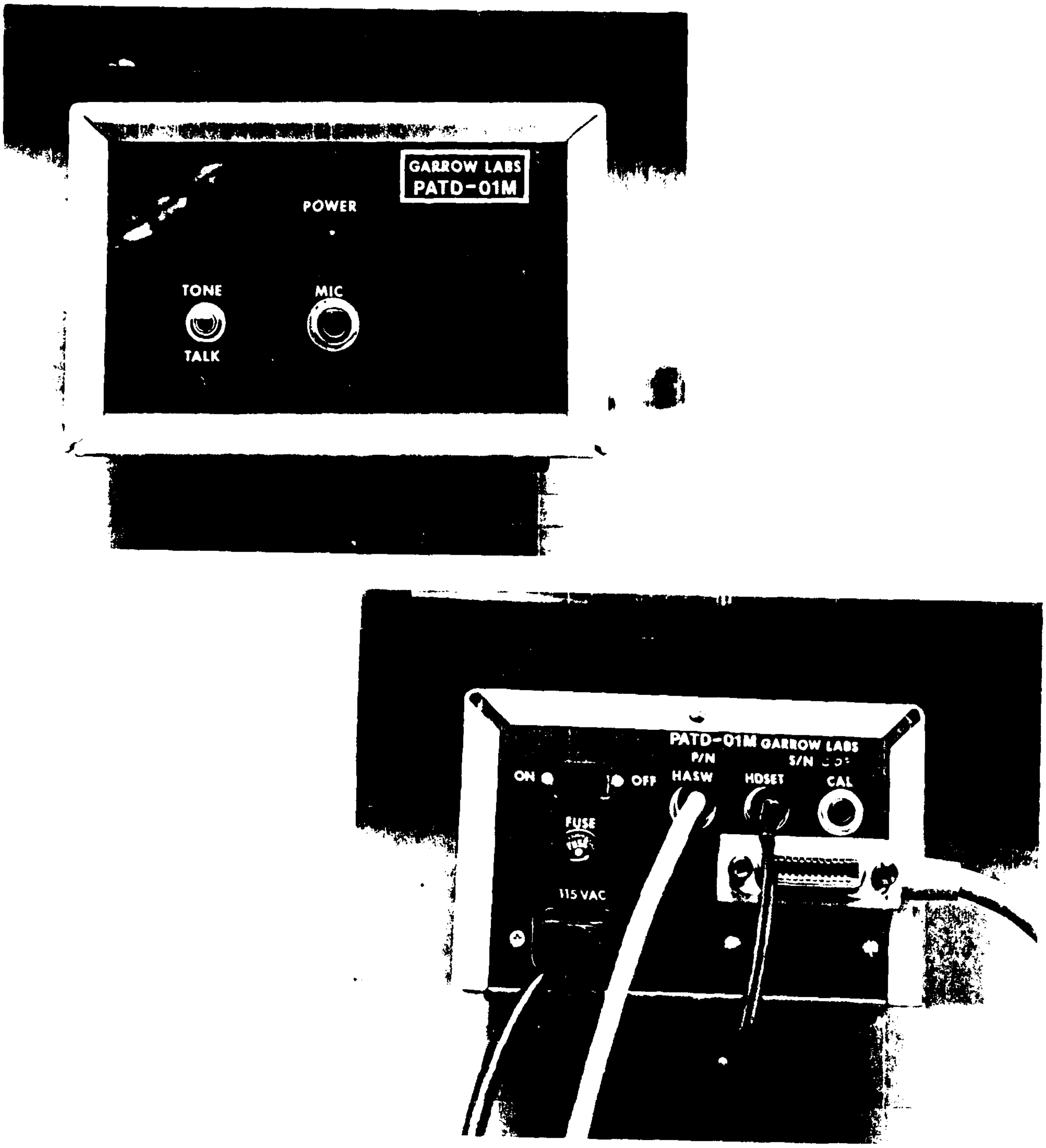
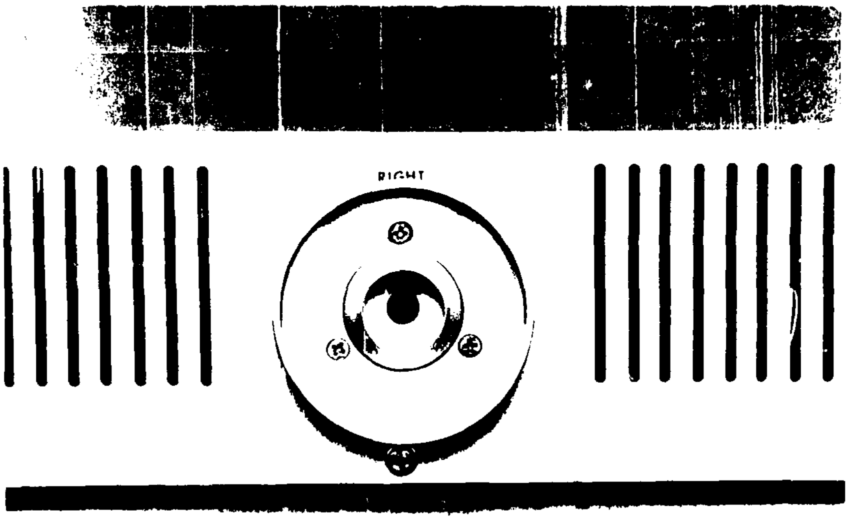



FIGURE 2. Front and rear panels of the microprocessor interface box, designated the Programmed audiometric threshold detector (PATD-01M). The front panel (upper left) contains a talk-to-patient microphone jack, a talk-to-patient or tone-presentation selector switch, and a power-indicator lamp. The rear panel (lower right) contains power switch, fuse holder, power-plug receptacle, hand switch and two headset (HDSET and CAL) jacks, and a IEEE-488 cable plug.



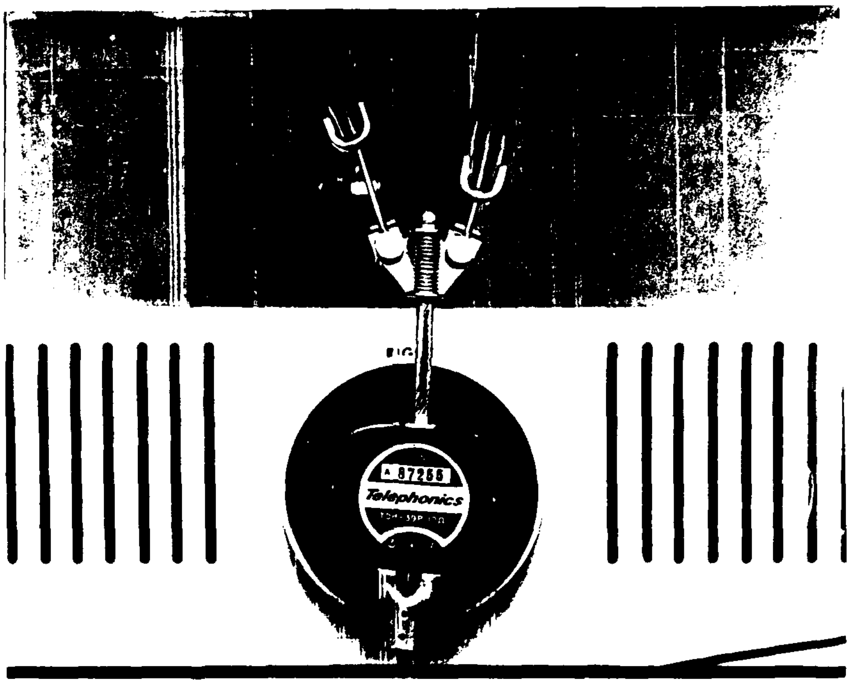




FIGURE 3. The right-earphone calibration coupler, shown on the side of the PATD microprocessor interface box, with and without the earphone in place.

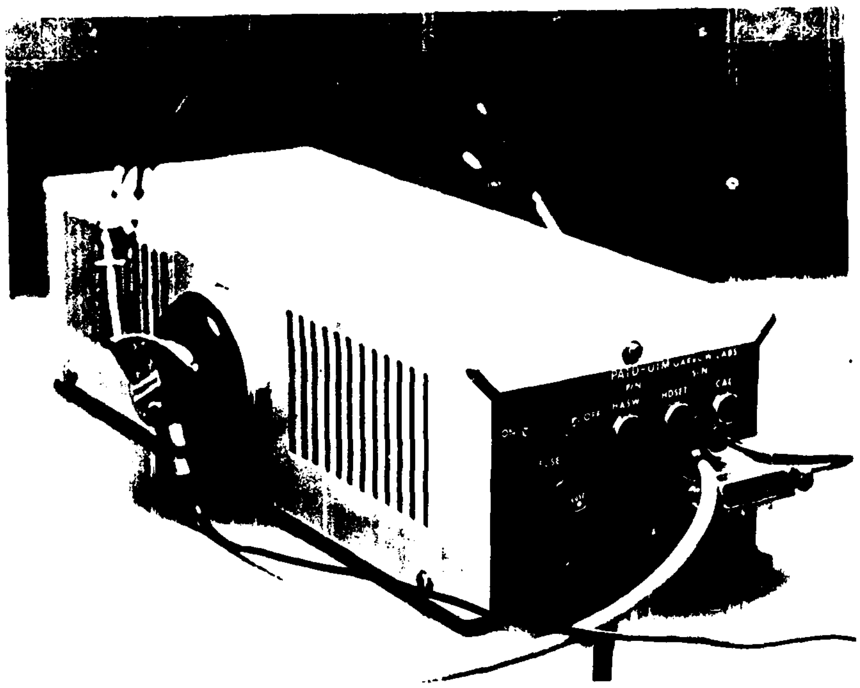
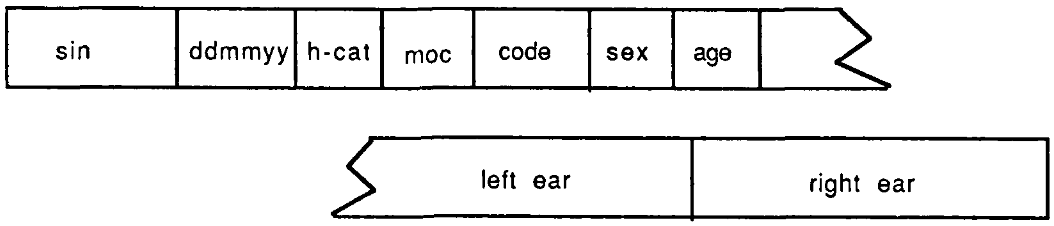


FIGURE 4. The PATD microprocessor interface box set up for an earphone calibration. The HDSET and CAL jacks are wired in parallel so that the earphone can be removed from inside the hearing-test booth and plugged into the CAL jack of the interface box during calibration.




**RECORD LENGTH -** 80 Characters

| **FIELD** | **LENGTH** | **TYPE** |
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| DATE | 6 | NUMERIC |
| HEARING CATAGORY | 1 | NUMERIC |
| MIL. OCC. CODE | 3 | NUMERIC |
| CODE | 3 | NUMERIC |
| SEX | 1 | ALPHA (F OR M) |
| AGE | 2 | NUMERIC |
| LEFT EAR | | |
| FREQ 1 TO 9 | 3 (EACH FREQ) | NUMERIC |
| RIGHT EAR | | |
| FREQ 1 TO 9 | 3 (EACH FREQ) | NUMERIC |

FIGURE 5. The format of a patient's hearing test record as stored in computer memory and on the system floppy disk.

# APPENDIX A

## HEARING-LEVEL TEST SEQUENCES

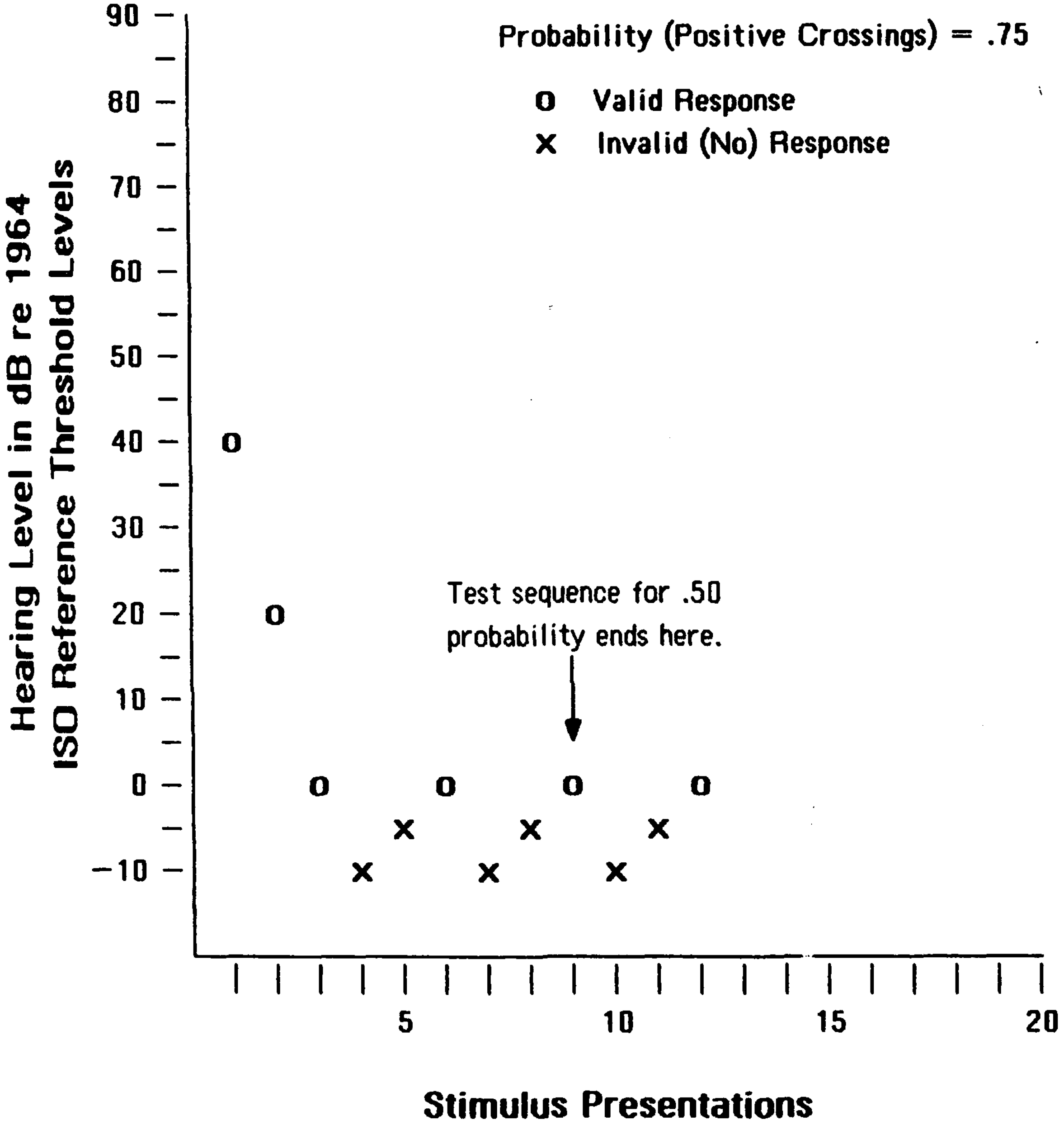


FIGURE A1. Hearing-level test sequence for a patient giving valid responses to all tone presentations above -5 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

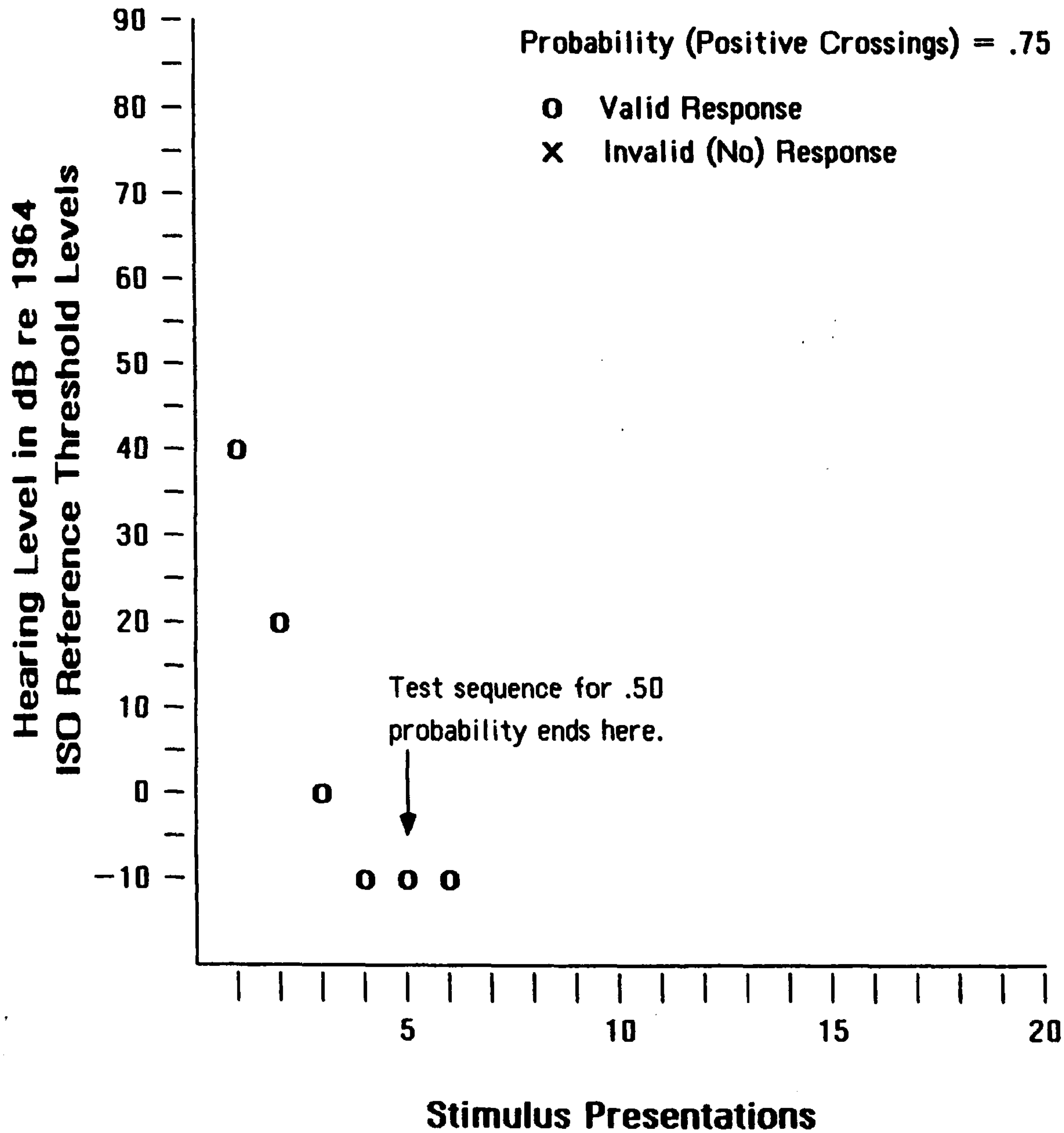


FIGURE A2. Hearing-level test sequence for a patient giving valid responses to all tone presentations. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

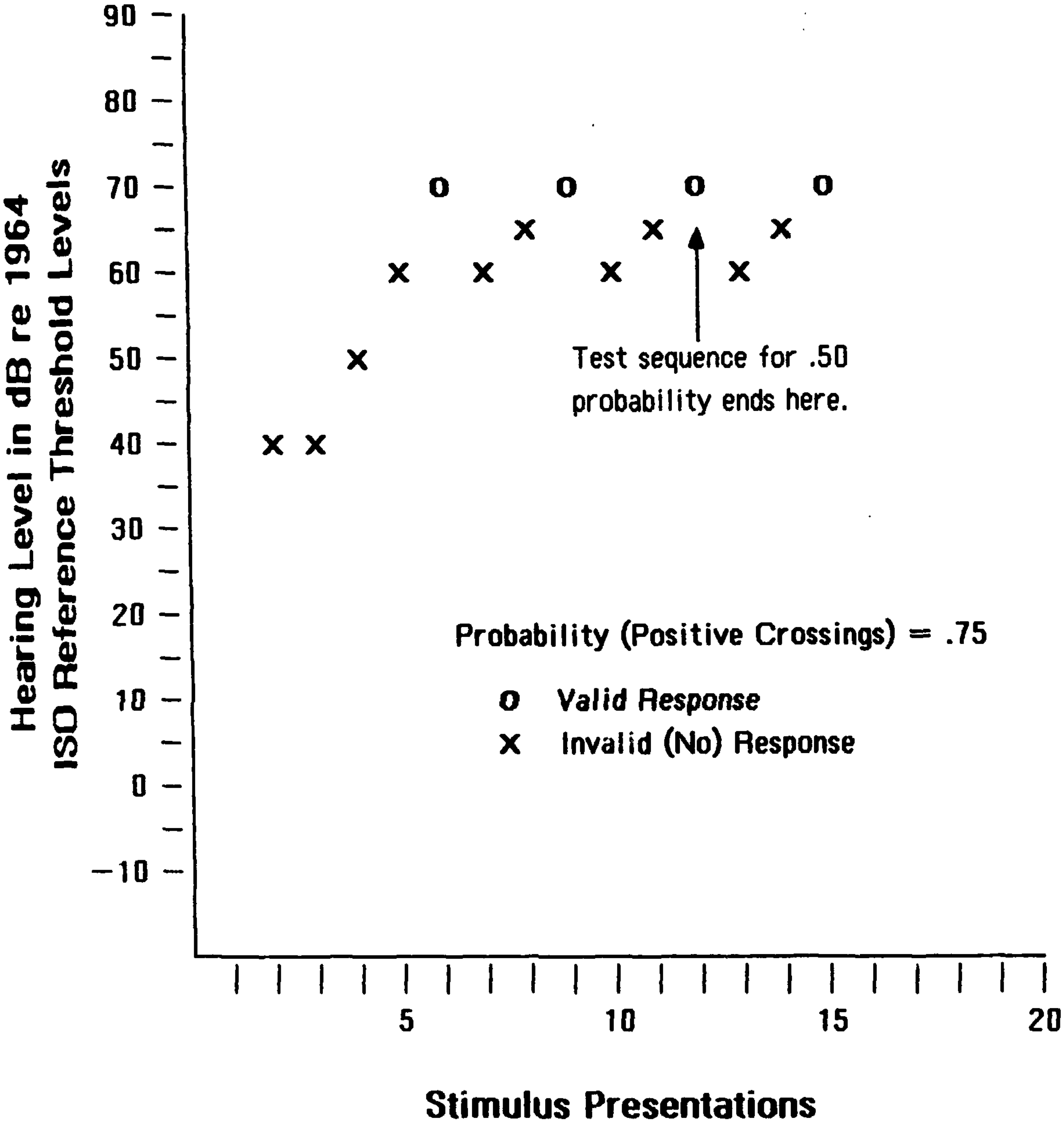


FIGURE A3. Hearing-level test sequence for a patient giving valid responses to all tone presentations above 65 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

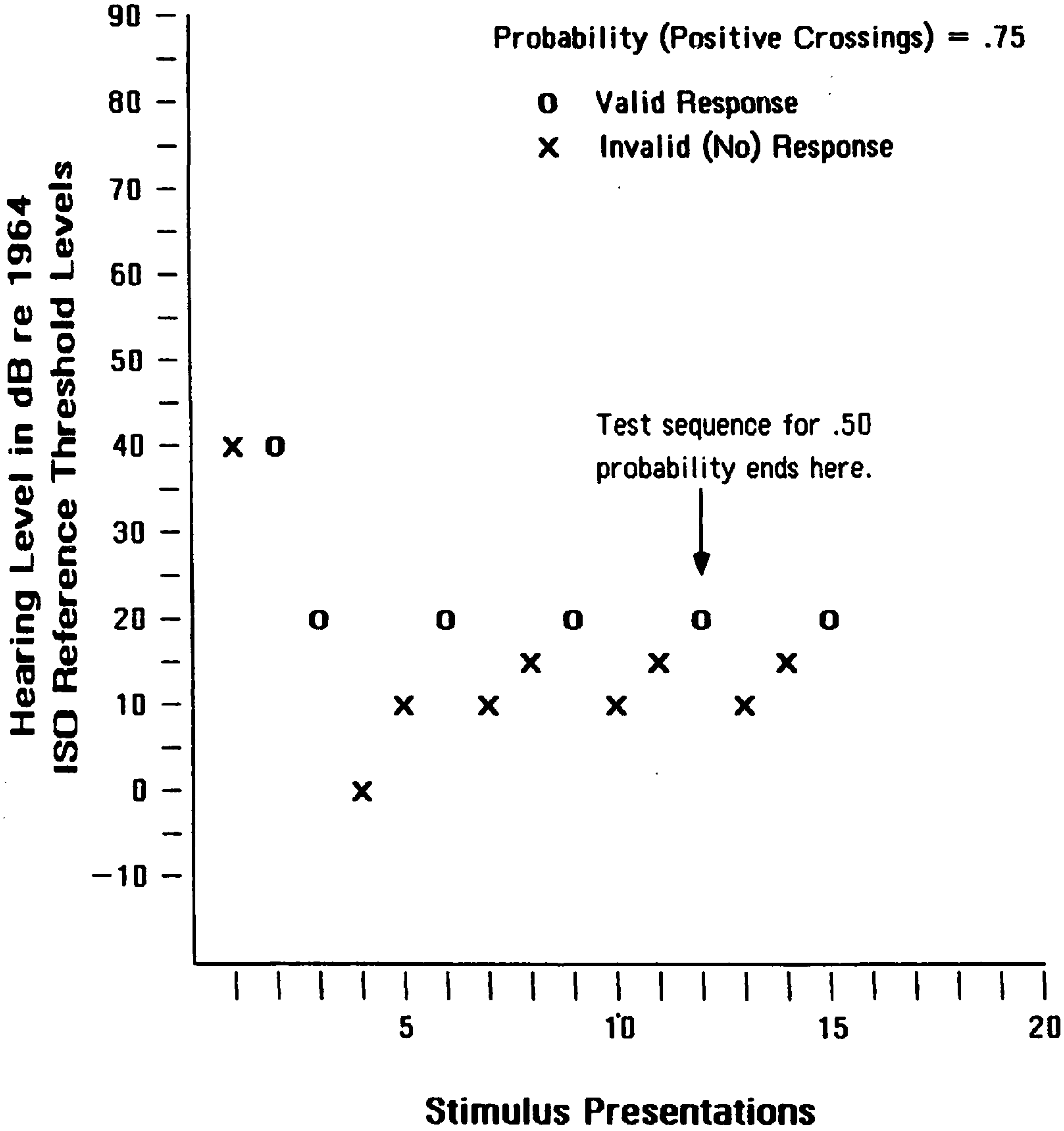


FIGURE A4. Hearing-level test sequence for a patient giving an invalid response to first tone presentation, valid responses to all other tone presentations above 15 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

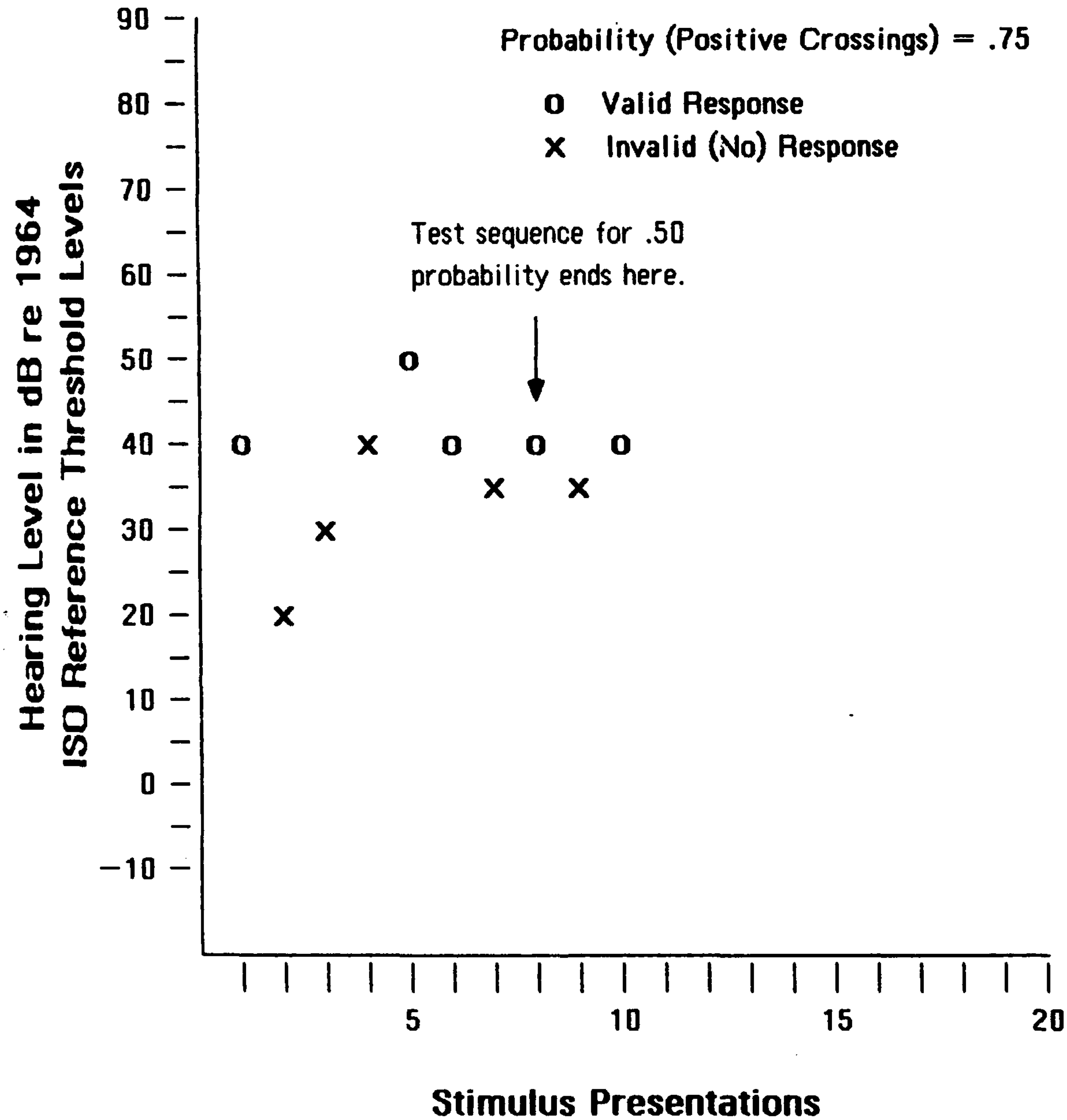


FIGURE A5. Hearing-level test sequence for a patient giving an invalid response at 40 dB in first ascending sequence, valid responses to all other tone presentations at 40 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

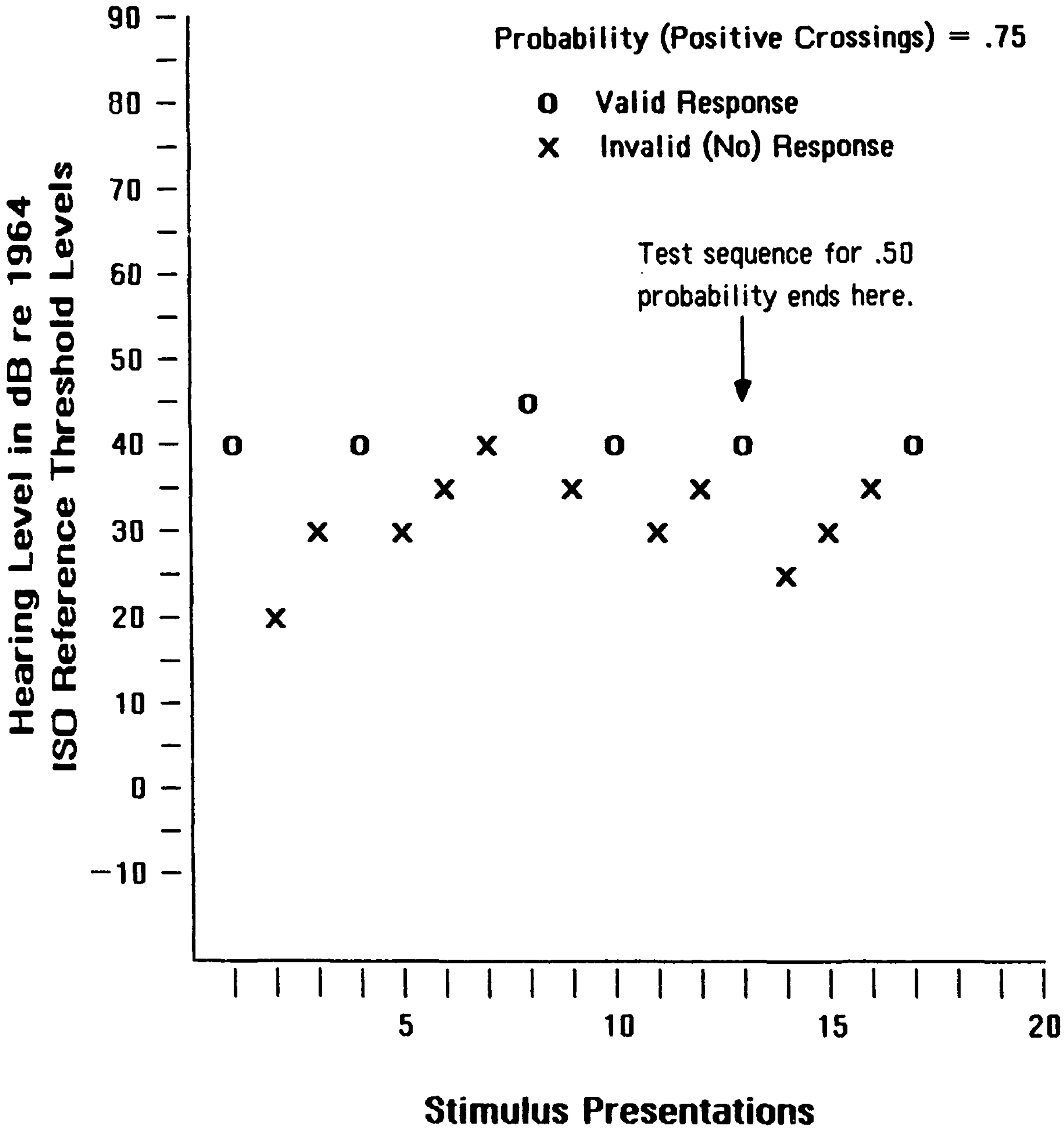


FIGURE A6. Hearing-level test sequence for a patient giving an invalid response at 40 dB in second ascending sequence, valid responses to all other tone presentations at 40 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

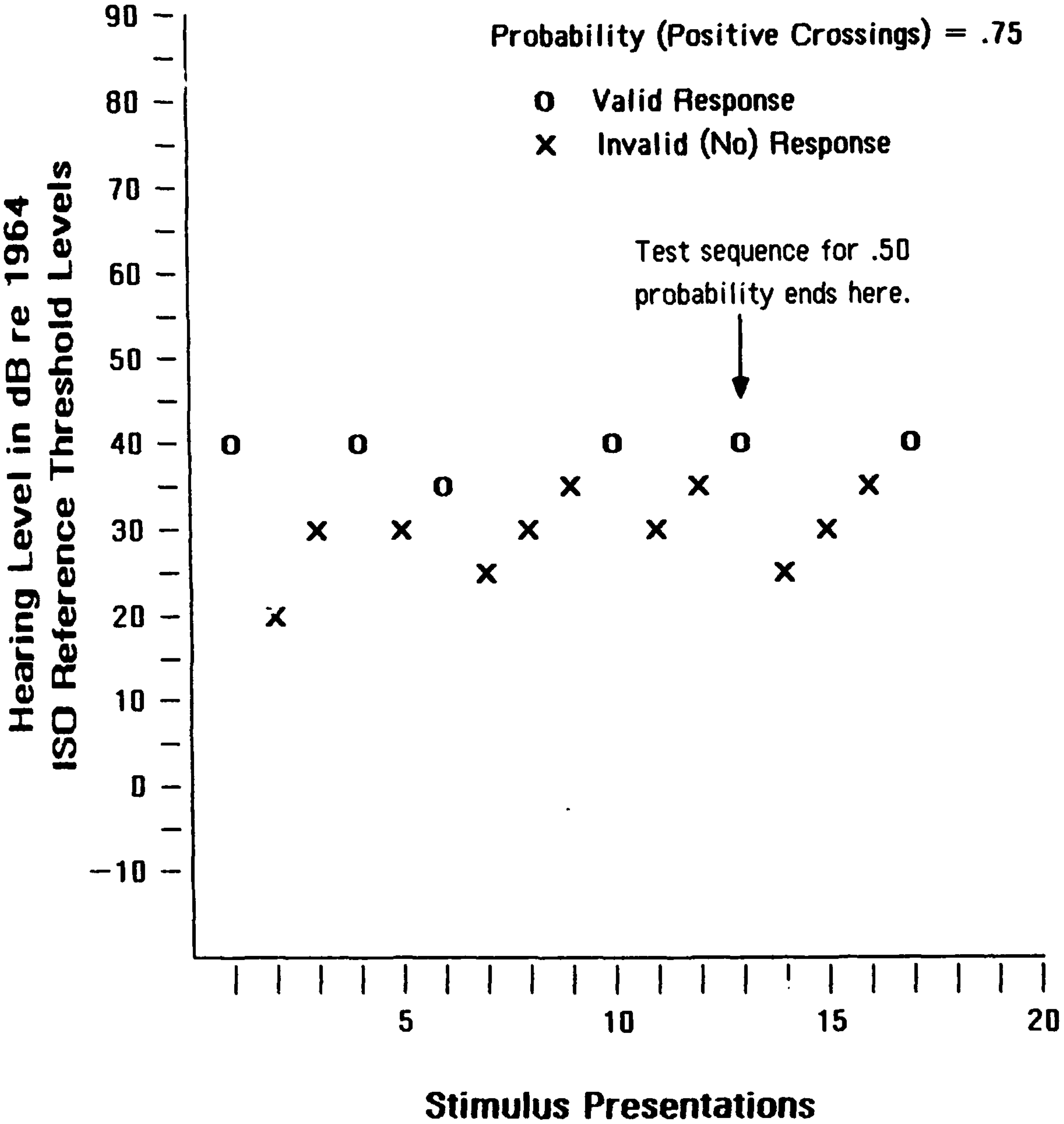


FIGURE A7. Hearing-level test sequence for a patient giving a valid response at 35 dB in second ascending sequence, valid responses to all other tone presentations above 35 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

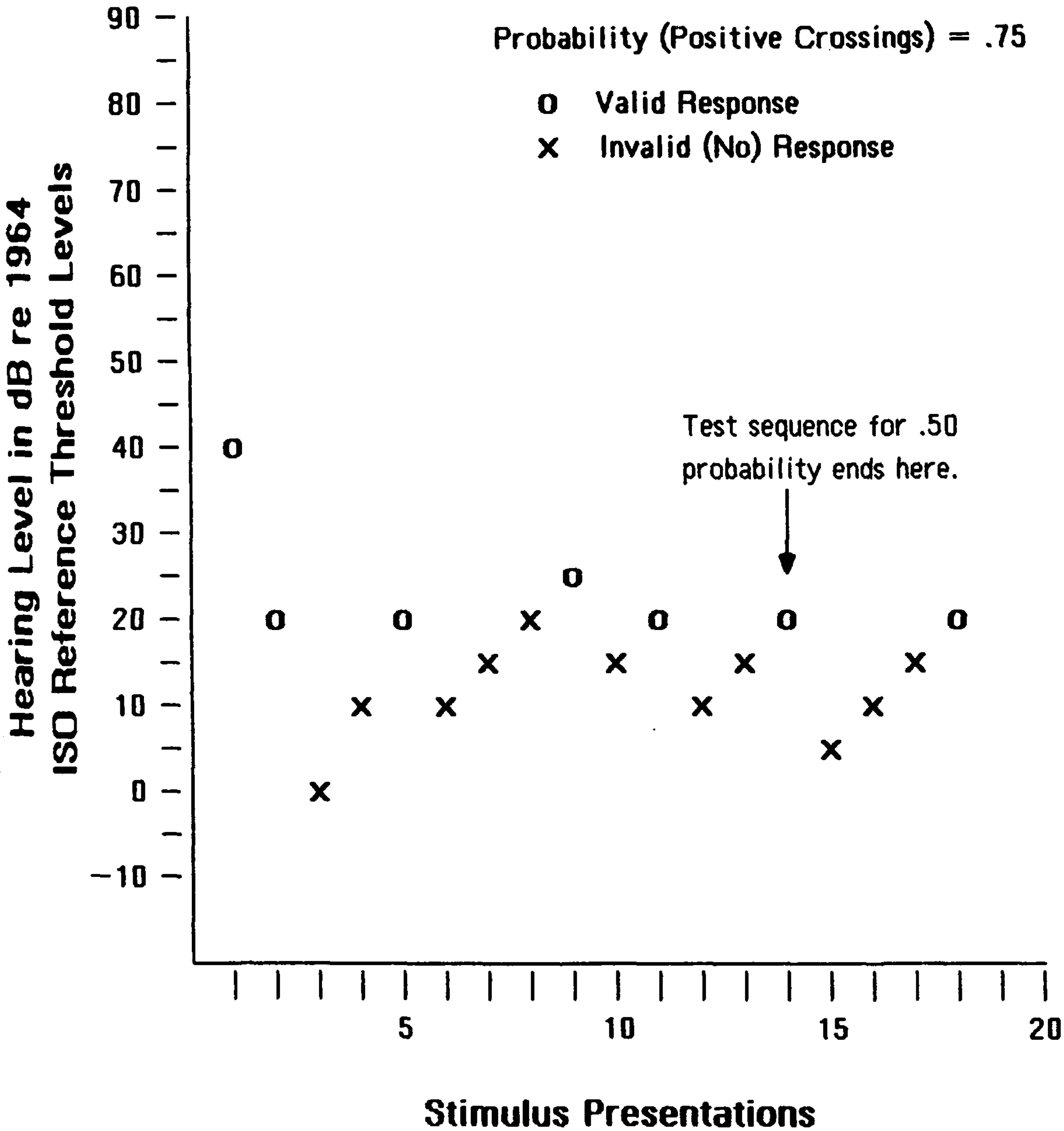


FIGURE A8. Hearing-level test sequence for a patient giving an invalid response at 20 dB in second ascending sequence, valid responses to all other tone presentations at 20 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

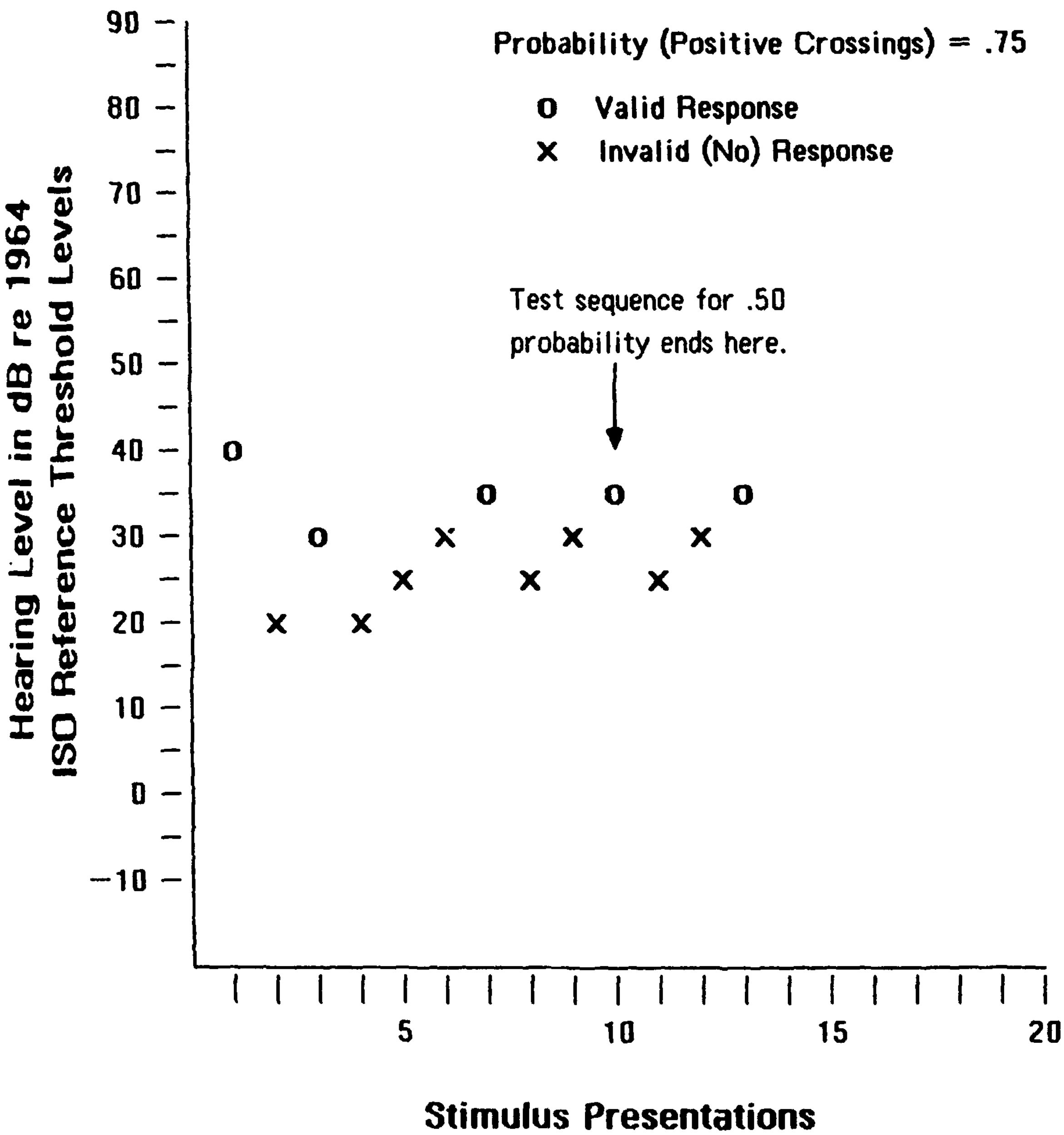


FIGURE A9. Hearing-level test sequence for a patient giving a valid response at 30 dB in first ascending sequence, valid responses to all other tone presentations at 35 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

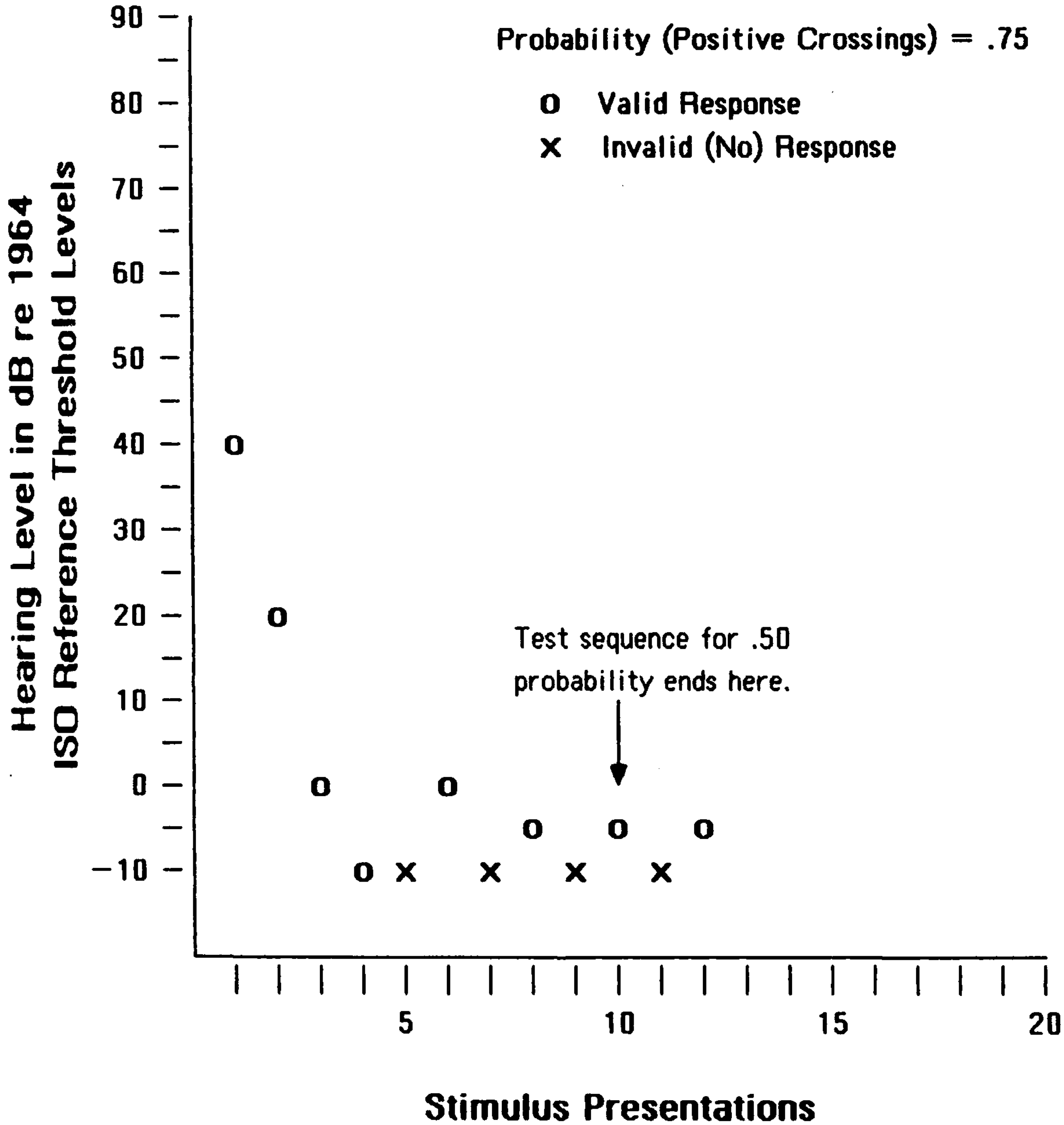


FIGURE A10. Hearing-level test sequence for a patient giving a valid response at -10 dB in first ascending sequence, valid responses to all other tone presentations at -5 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

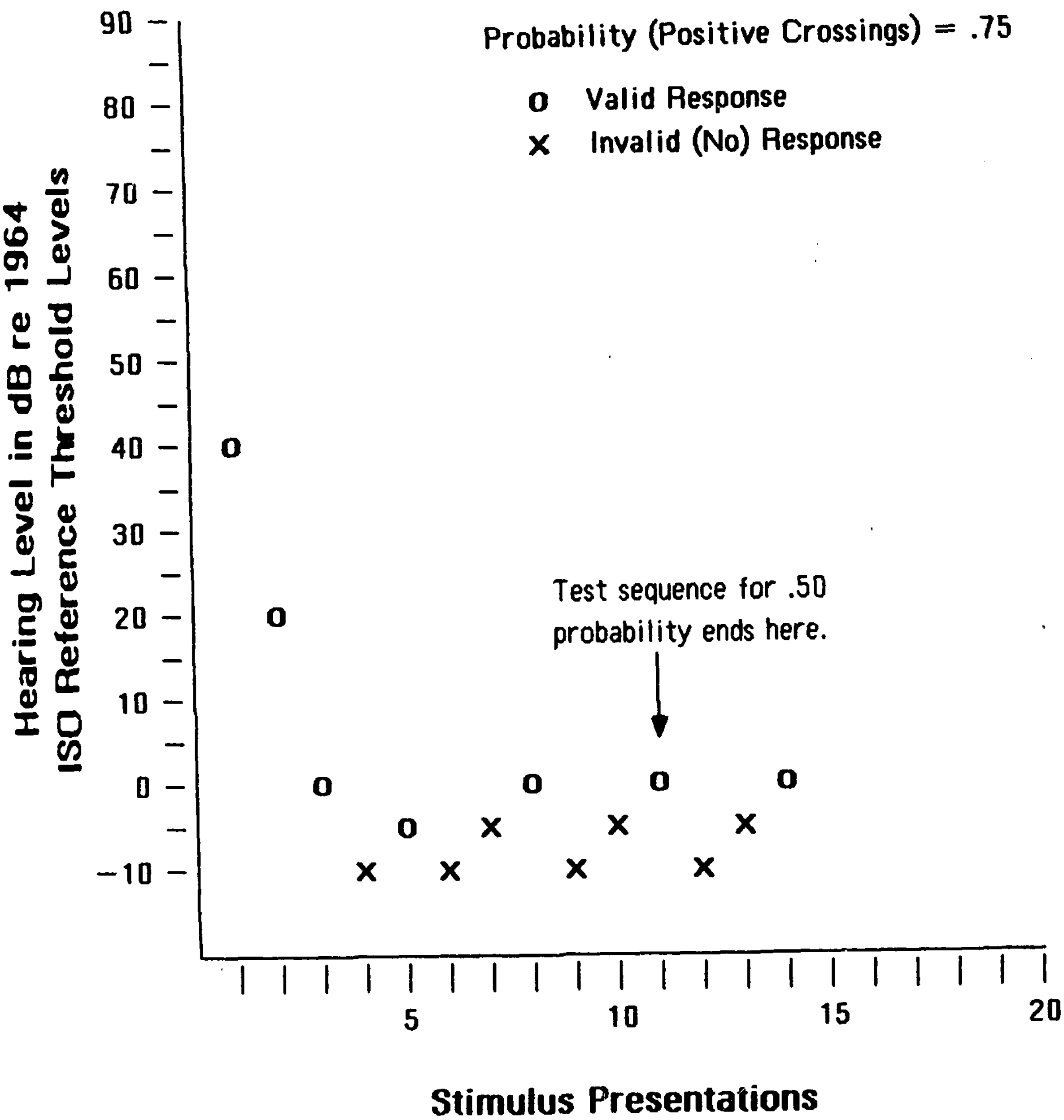


FIGURE A11. Hearing-level test sequence for a patient giving a valid response at -5 dB in first ascending sequence, valid responses to all other tone presentations at 0 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

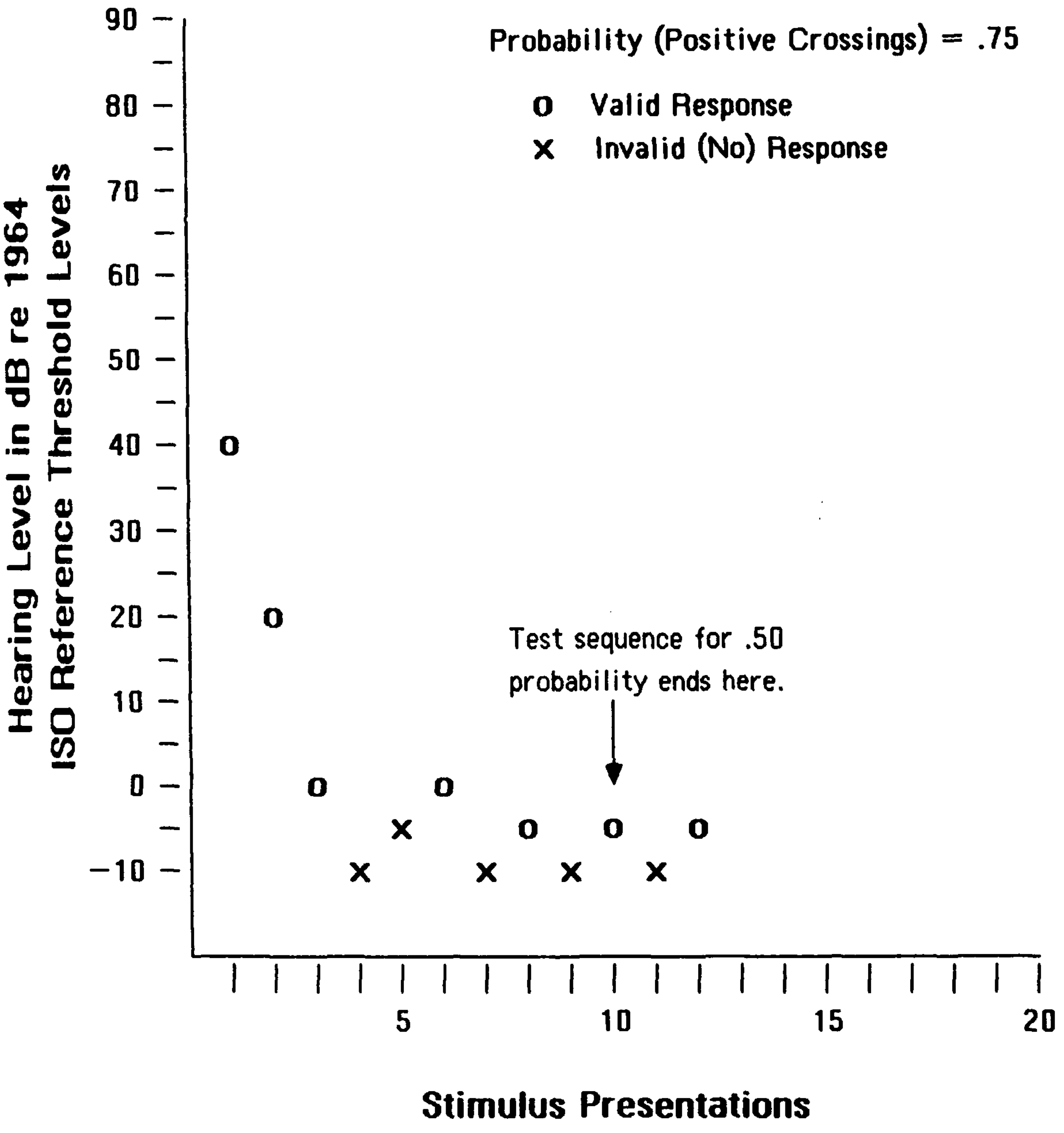


FIGURE A12. Hearing-level test sequence for a patient giving a valid response at 0 dB in first ascending sequence, valid responses to all other tone presentations at -5 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

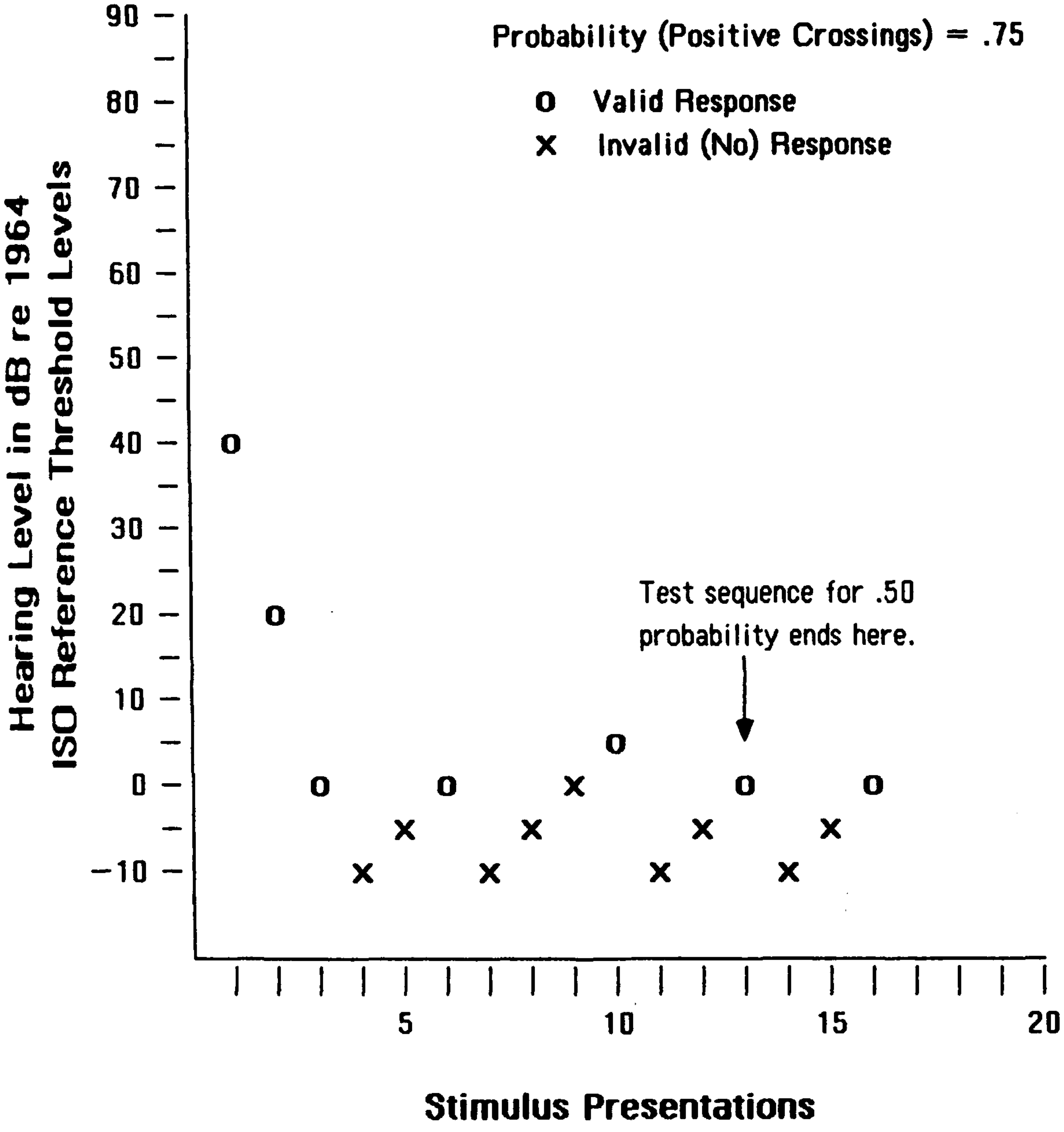


FIGURE A13. Hearing-level test sequence for a patient giving a valid response at 5 dB in second ascending sequence, valid responses to all other tone presentations at 0 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

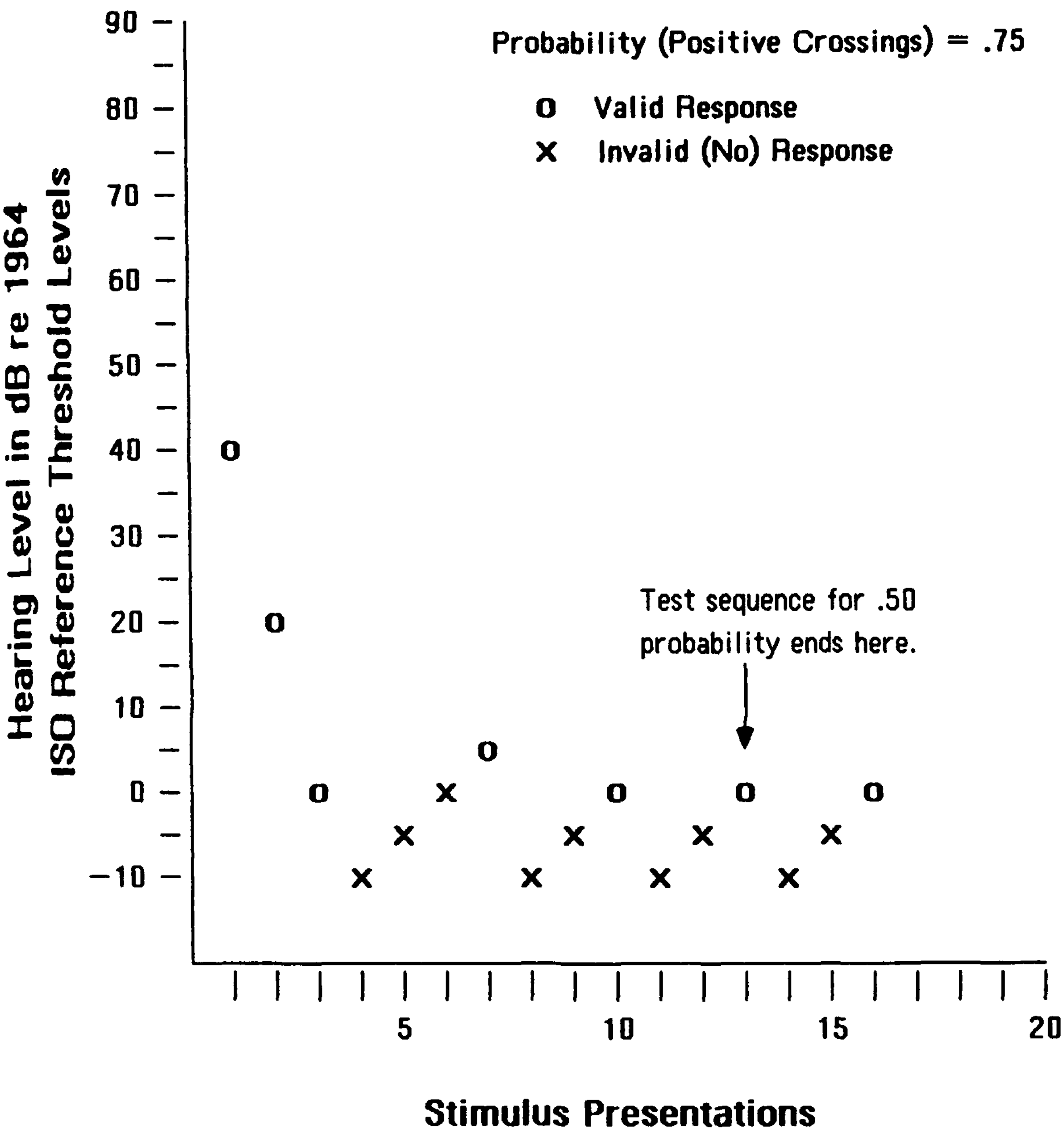


FIGURE A14. Hearing-level test sequence for a patient giving a valid response at 5 dB in first ascending sequence, valid responses to all other tone presentations at 0 dB. The .75 threshold detection is the lowest tone-presentation level that elicits three valid responses during ascending hearing-level (positive-crossing) sequences. The .50 threshold detection requires two valid responses during ascending hearing-level sequences.

# APPENDIX B

## THRESHOLD-DETERMINATION PROGRAM FLOW-DIAGRAMS

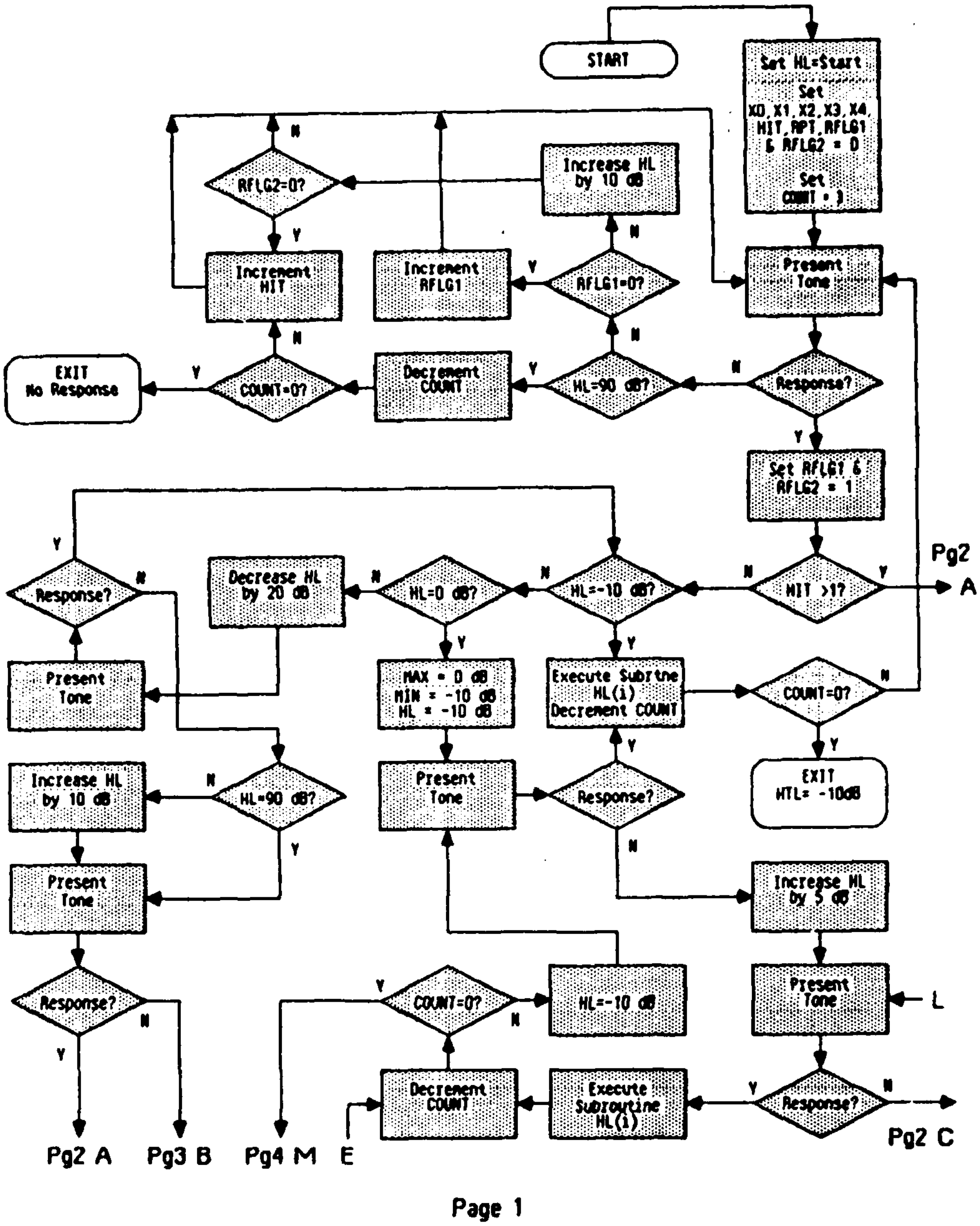


FIGURE B1. Threshold-determination main program (Pg 1 of 5).

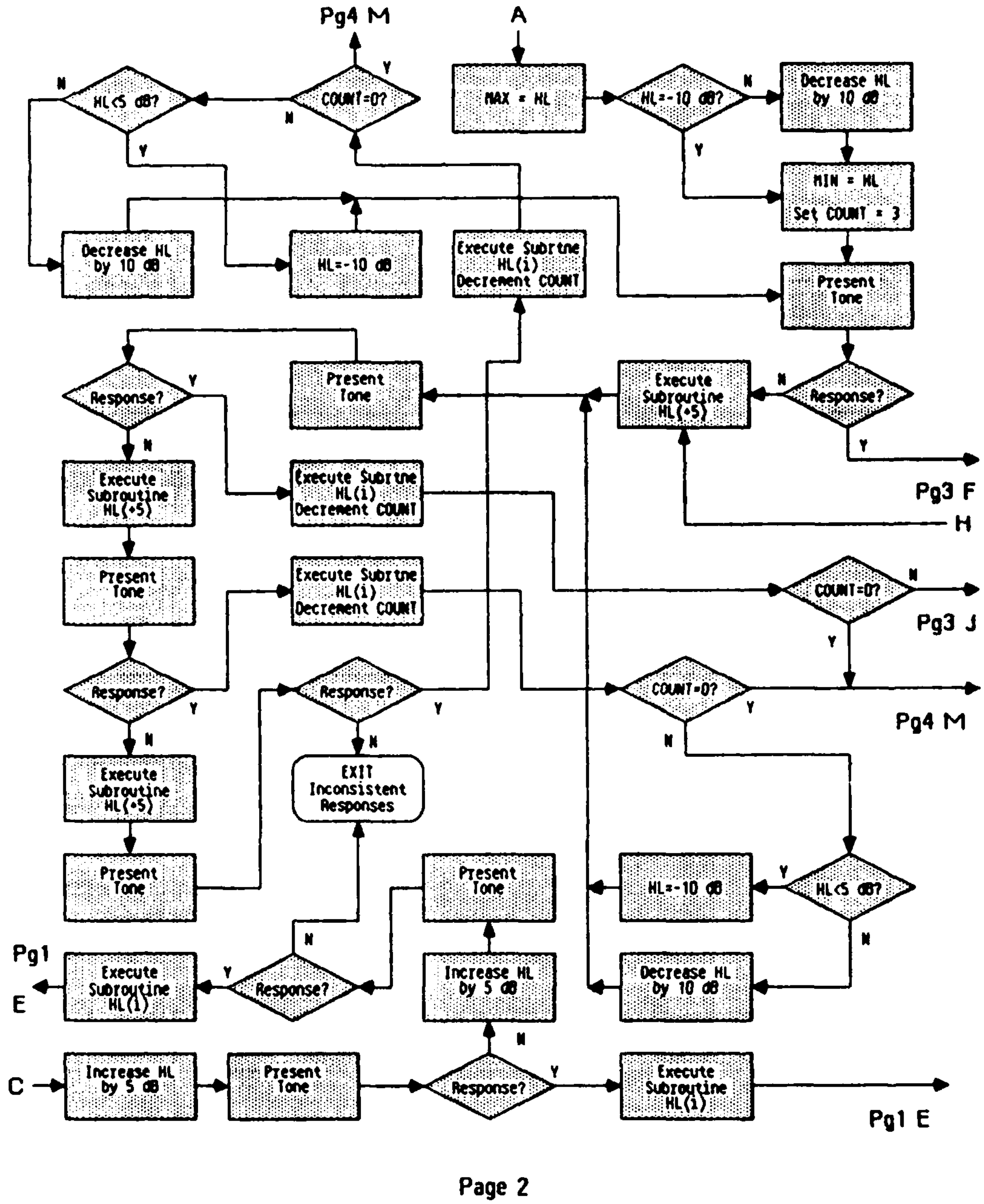


FIGURE B2. Threshold-determination main program (Pg 2 of 5).

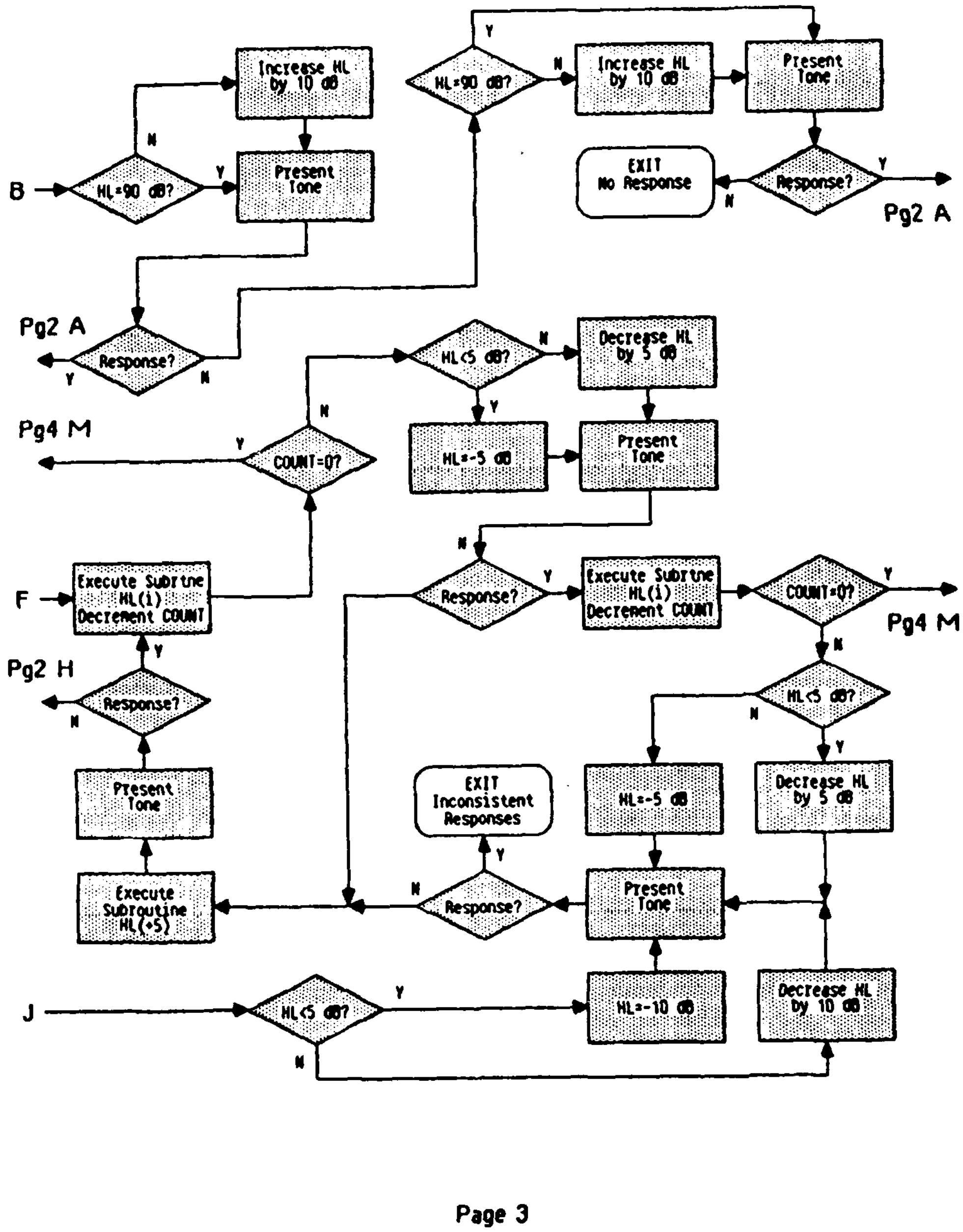


FIGURE B3. Threshold-determination main program (Pg 3 of 5).

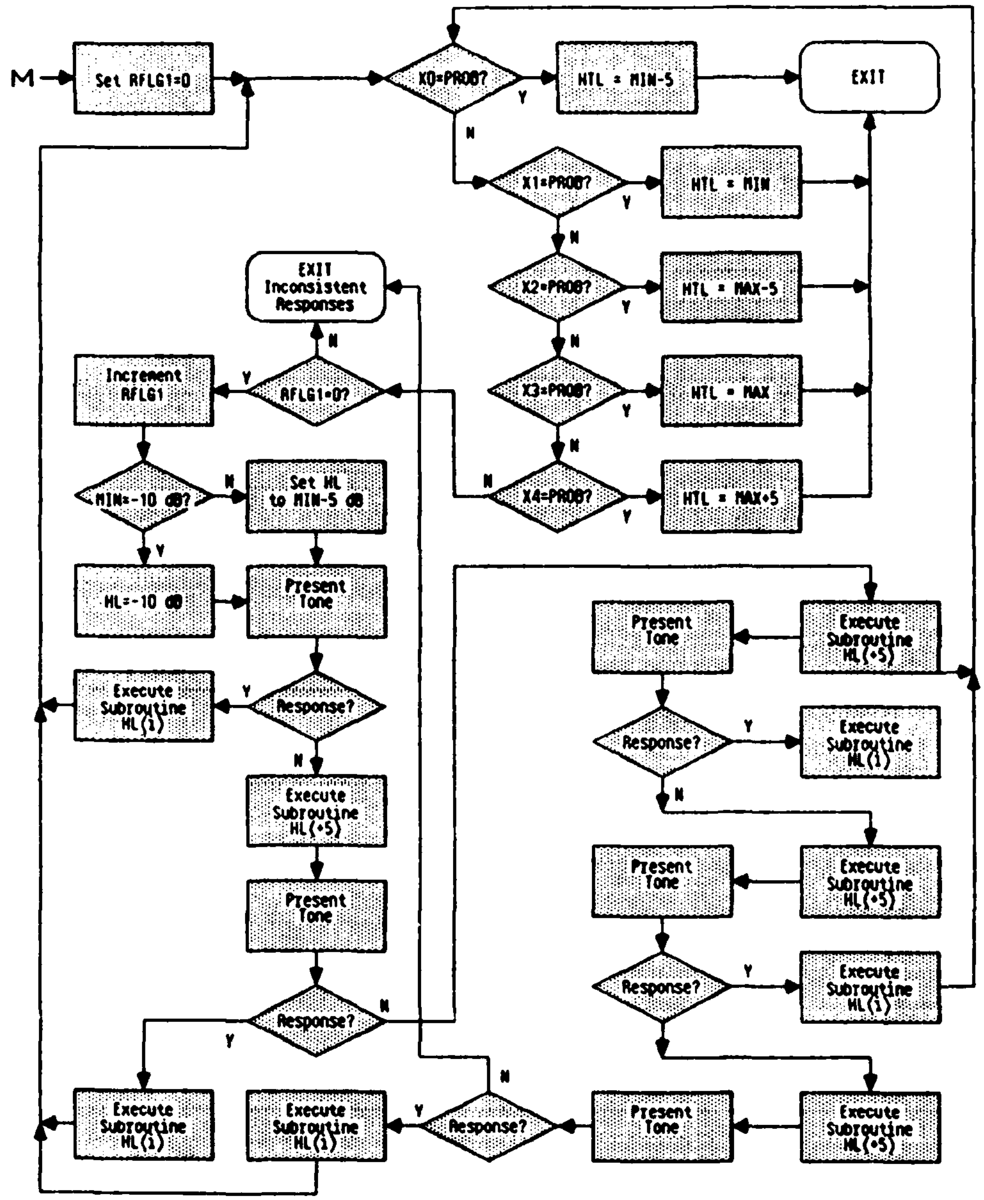


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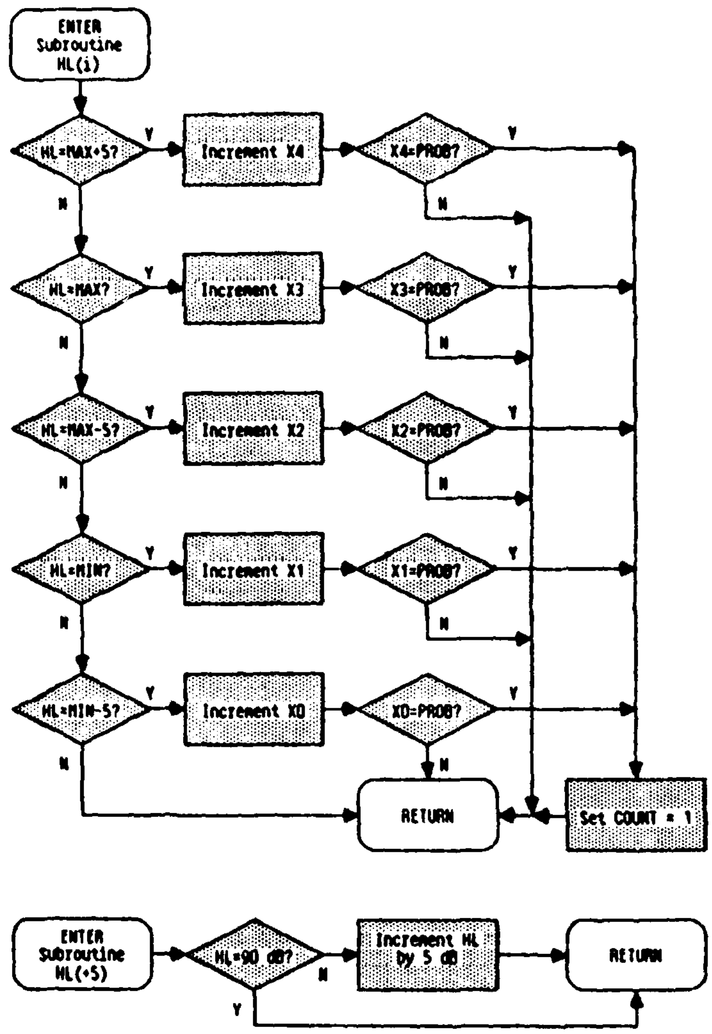
FIGURE B4. Threshold-determination main program (Pg 4 of 5).

SUBROUTINES




**Page 5**

FIGURE B5. Threshold-determination subroutines (Pg 5 of 5).

# APPENDIX C

## OPERATION AND CALIBRATION OF THE MICROPROCESSOR-CONTROLLED AUDIOMETER

## 1. STARTING A TEST

1.1 After placing the program test disk on DRIVE 0 of the disk drive, depress the terminal SHIFT key and while holding it down, press the RUN/STOP key. This loads the program into the microprocessor memory and then runs it. As the circuitry of the interface box is self-testing, a series of tones will be heard if the headset is attached. The following prompts or messages will appear on the screen:

**Unit passed self-test.**
**Headset calibration required?**

1.2 The first line will be displayed on the screen if the interface box is functioning correctly. If the test fails, an appropriate message will be displayed. Type 'y' if a headset calibration is required. A prompt on the screen will instruct the technician to place the earphones on the calibration couplers on the sides of the interface box (Figures 3 and 4), the right (red) earphone on the right coupler and the left (blue) earphone on the left coupler, and the headset plug inserted into the HDSET or CAL jack on the back of the interface box. The calibration should be performed at least once a week, at the beginning of the test day. If an earphone calibration is not wanted, type an 'n'. The calibration is carried out at the test frequencies between 250 and 8000 Hz inclusive. If the headset does not calibrate correctly, the headset should be checked to ensure that the earphones are mounted correctly on the calibration couplers. Otherwise the headset should be replaced and/or the total system recalibrated (see Section 6). The calibration can be restarted by pressing the RUN/STOP key.

**Press any key to start testing!**

1.3 A hearing test is initiated by pressing any key on the terminal, as instructed on the screen. A menu will appear on the screen presenting the default test-parameters (highlighted): test frequencies, probability (threshold detection criterion (.50 or .75, see paragraph 2.2)), stimulus-tone sequence (pulsed or continuous), and the starting level of the tone sequences (Figure C1). Standard CF screening practice is to not test hearing at 125 and 250 Hz, as indicated by the default test frequencies in the parameter menu. At the bottom of the menu display is the question:

**ALL FIELDS O.K. ? □**

1.4 If changes are required to the test conditions, type 'n' and follow the edit instructions given on the screen (Figure C1). If, after making the changes, the cursor □ is not positioned after the question 'ALL FIELDS O.K. ?' press the CLR/HOME key until it is positioned there and then type 'y'. A blank audiogram will be displayed on the screen with a test-date prompt (Figure C2).

**TEST DATE [M]M/DD/YY**

1.5 The required information is entered by typing over the highlighted character [M], which then moves to the next date character. When the sixth character has been typed in, the screen will display a second line of requested information: the patient's Social Insurance Number (S.I.N., 9 characters), Military Occupation Code (MOC, 3 characters), a three digit code, and the patient's age and sex. When the data-input has been completed, the screen will display the question (Figure C3):

**ALL DATA O.K. ? □**

1.6 If a mistake has occurred in entering the data, respond by typing 'n'. The cursor □ will be repositioned over the S.I.N., and all subsequent information must be re-entered. When the information is correct, type 'y'. This will be followed by the prompt (Figure C4):

**AUTO OR MANUAL ? □**

1.7 Under most circumstances, the test will be run in the automatic mode. This is accomplished by typing 'a'. To run the test in the manual mode, type 'm'. The test will begin with the appearance of the message:

**TEST IN PROGRESS**

2. <u>AUTOMATIC TESTING</u>

2.1 In the automatic-test mode, the left ear is tested first. The first threshold-determination in each ear is a 1000-Hz (1K) reference test. This is followed by threshold determinations at the frequencies highlighted in the parameter menu (Figure C1) in order if ascending frequencies. The threshold obtained at 1000 Hz in this sequence must be within ±5 dB of the value obtained with the reference test. Otherwise, the test will be interrupted, a series of beeps will alert the technician, and a menu line will be printed at the the bottom of the screen (Figure C5). One of these options may be selected by typing the highlighted letter. The options are defined as follows:

**[Q]UIT** - The test will stop and the program will be unloaded. In order to restart, the test program must be reloaded. Any data which has been collected for the patient up to this point will be lost.

**[R]EPEAT FREQ** - The tone-presentation level of current test frequency will be reset to the starting tone-presentation level and the test will be repeated in the AUTOMATIC mode. This option should not be selected if the program interrupts during the 1000-Hz reference test or during a threshold test in which the patient's responses are inconsistent (see paragraph 2.2). Rather, a check should be made to ensure that the patient understands the test procedure and is responding appropriately, or that the patient is not being distracted by extraneous noise. Secondly, ensure that the tones are actually being presented through the headset. Then restart the test by selecting the REPEAT TEST option. If the patient continues to have trouble, it may be necessary to select the MANUAL option.

**[N]EXT EAR** - This option is selected only if the left ear is being tested. The testing will immediately switch to the right ear, beginning with the 1000-Hz reference test. Once the right ear has been selected, the program will not return to the left ear. If the technician does wish to complete testing the left ear before moving on to the right, the MANUAL option be selected.

**[R]EPEAT TEST** - This option will repeat the entire test starting with the left ear.

**[N]EXT TEST** - The selection of this option will cause the test to finish prematurely. However, the data for the patient will be stored in its incomplete form. The display screen will then prompt **PRINT AUDIOGRAM ?** □. Respond with 'y' or 'n' as appropriate. A menu line will then be displayed with the following options:

**[E]XIT** - The program is stopped and unloaded. To rerun the program press the terminal SHIFT key and, while holding it down, press the RUN/STOP key.

**[N]EXT SUBJECT** - The program begins prompting for information on the next patient, asks if the data is okay, displays **AUTO OR MANUAL ?** □ as described previously, and lastly, begins testing the patient.

**[R]ESTART** - Selecting this option causes the default test-parameter menu to be displayed. This option is used the test parameters are to be changed.

**[M]ANUAL** - This option activates the MANUAL TEST mode and displays the following

instructions at the bottom of the screen for controlling the stimuli and test results:

**[4]=LEV DOWN, [6]=LEV UP, [2]=FREQ DOWN, [8]=FREQ UP, [0]=OTHER EAR PRESS SPACE FOR STIM, RETURN TO SET THRESHOLD AND ESC TO END**

That is, the terminal-keypad character '4' reduces the stimulus level by 5 dB, the terminal-keypad character '6' increases the stimulus level by 5 dB, the terminal-keypad character '2' reduces the frequency of the test tone to the next test frequency highlighted on the test-parameter menu, the terminal-keypad character '8' increases the frequency of the test tone to the next test frequency highlighted on the test-parameter menu, the terminal-keypad character '0' switches the test to the other ear, pressing the terminal SPACE-BAR presents the stimulus, and pressing the RETURN key enters the current stimulus-level into the patient's data file as the threshold at the active test frequency.

When entering the MANUAL test mode, the test will begin at the frequency which was interrupted. Pressing the terminal ESC key returns the program to the automatic mode and testing resumes at the next frequency to be tested.

**2.2** Threshold is defined as the lowest signal level (hearing level (HL)) at which responses occur in at least one-half of a series of intensity-ascending trials with a minimum of either three responses out of four required at a single level (defined herein as *75 per cent threshold detection),* or two responses out of four (defined as *50 per cent threshold detection)(see paragraph 1.3).* If, after a set number of ascending trials, the patient has not responded consistently due to inattention, tinnitus, etc., the automatic test will interrupt, a series of beeps will alert the technician, and a menu line and options described in paragraph 2.1 will be printed at the bottom of the screen (Figure C5).

**2.3** If at any time the technician wishes to interrupt the automatic test, the terminal ESC key is to be pressed, resulting in the menu of options described in paragraph 2.1. The completion of an automatic test is signaled by a series of beeps, the results of the test are displayed on the screen and stored on the disk, and the prompt **PRINT AUDIOGRAM ? □** appears at the bottom of the display (Figure C6). A printout (Figure C7) is accomplished by typing 'y'. See the FILE EDITOR (Section 5) for further print-out and editing information. After completion of the printout, an addition prompt will be displayed:

**[E]XIT, [N]EXT [S]UBJECT, OR [R]ESTART ? □**

**2.4** To select an option type the appropriate highlighted letter. The function of each option has been described previously.

3. MANUAL TESTING

**3.1** After the MANUAL test mode has been selected, the following lines will appear near the bottom of the screen:

**TEST IN PROGRESS : F=125 40 DB RIGHT EAR**

**[4]=LEV DOWN, [6]=LEV UP, [2]=FREQ DOWN, [8]=FREQ UP, [0]=OTHER EAR PRESS SPACE FOR STIM, RETURN TO SET THRESHOLD AND ESC TO END.**

**3.2** The function of the control keys has been described previously in paragraph 2.1. Tone-stimulus ON and patient responses can be observed by highlighted indicators ([S], [R]) on the terminal screen, immediately to the right of the highlighted 'LEFT/RIGHT EAR' indicator (see Figures C8 and C9). When testing has been completed, pressing the ESC key will exit the program from MANUAL mode and produce the prompt:

**PRINT AUDIOGRAM ? □**

3.3 See paragraph 2.2 for audiogram printing.

4.0 FILE ORGANIZATION

4.1 When an audiogram is completed (see paragraphs 2.2 and 3.2), the data contained therein are stored automatically on floppy disk in a file designated by the date MMDDYY (e.g., 060185, see paragraph 1.5). That is, all audiograms bearing the date 060185 that have been entered on a given disk will be in the file named 060185. Individual audiograms (records) within the file are identified by patient Social Insurance Number (SIN).

4.2 Periodically, the individual date-files on a disk should be concatenated into a master file in order that searching for patients' records can be carried out across date-files. To concatenate the file 060185 to the master file, type

concat "060185" to "master"

followed by a RETURN *. To retrieve a patient's audiogram(s), refer to paragraphs 5.3 and 5.4.

5.0 FILE EDITOR

5.1 The editor program allows the technician to enter audiograms which were obtained previously at another site or with another audiometer. It also permits the printing of patients' audiograms which are recorded on the system. To run this program, type the commands below, each followed by a RETURN:

**dL"editor"**

**run**

5.2 The following lines will then be displayed on the screen of the terminal:

**FILE MAINTENANCE PROGRAM**
**********************************

**[P]RINT, [C]REATE, [A]DD OR [H]ELP ? [H]**

To select one of the options in the EDIT MENU, press the appropriate highlighted letter. The default option is [H]ELP, as shown. A description of each option follows:

5.3 **[P]RINT** - This option in the EDIT MENU allows the technician to obtain a printout of a patient's audiogram. The following three prompts will appear; type in the required information followed by a RETURN.

**ENTER FILENAME:** - If the test date of the patient's audiogram is known, it can be used as the filename (format MMDDYY). Otherwise, type 'master', which will present sequentially the audiograms currently on the disk.

**ENTER SUBJECT'S NAME:** - self explanatory.

**ENTER SOC. INSC. NO. (C/R=END) [0]** - The required SIN is entered by typing over the highlighted character [0], which then moves to the right as a prompt in turn for each of the remaining characters. The string '(C/R=END)' allows a RETURN to exit the program out of the the print-option mode, after which the EDIT MENU will be presented again.

* The expression 'RETURN' indicates that pressing the terminal RETURN key is required.

5.4 After entry of the SIN, the system will display the contents of the patient's record on the screen. To print the audiogram shown, follow the first instruction found at the top of the screen. Because there are occasions when a patient may have been tested more than once on a particular day, follow the second instruction to reach the required audiogram. If the requested audiogram cannot be found, the system will display the following message:

**PROGRAM TERMINATED**
**ALL DONE ? [Y]**

To return to the EDIT MENU, type 'n' over the highlighted [Y].

5.5 **[C]REATE** - This option in the EDIT MENU creates a new file and permits the entry of data into the file from audiograms obtained previously at another site or with another audiometer. If the system is DATE PROTECTED to prevent audiometric data from being *inappropri :tely* entered into the system, the manual entry of hearing-test results dated on or after the installation of the system at a given CFB site will be aborted. Should an attempt be made to enter such data on a DATE-PROTECTED system, the following message will appear on the screen:

**YOU CANNOT CREATE FILES WITH CURRENT DATES.**
**USE THE AUTOMATIC TEST PROGRAM**

**PROGRAM TERMINATED. ALL DONE ? [N]**

5.6 If the date is accepted, a menu will appear on the screen and the cursor □ will be positioned at the first data entry point. The required information can be entered by typing over the cursor □ and terminating with a RETURN. The cursor □ will then skip to the next data entry position. If an error is made, use the INST/DEL key to delete the character and continue, or type over the character if the data field is only a single character long.

5.7 When the patient's data entry has been completed, press the SHIFT key and while holding it down, press the RETURN key. The screen will be refreshed, and data for another patient may be entered. To exit from the CREATE program, press the SHIFT key and while holding it down press the CLR/HOME key. The data will be written to the disk and the following prompt will appear:

**PROGRAM TERMINATED**
**ALL DONE ? [Y]**

If finished, press the RETURN key. Otherwise type 'n', which will bring the EDIT MENU back to the screen.

5.8 **[A]DD** - This option in the EDIT MENU allows the addition of audiogram data (records) to files which have been created previously using the CREATE option. After selecting this option, enter the file name as requested. Data are entered as described in paragraphs 5.6 and 5.7.

5.9 **[H]ELP** - This option in the EDIT MENU will display a brief description of the three previously described options. Striking any key will return to the menu display.

## 6. AUDIOMETER CALIBRATION PROCEDURE

6.1 An audiometer calibration is required whenever new earphones are to be used with the system, or whenever previously calibrated earphones do not pass the system calibration test (see paragraph 1.2). In addition to the complete micro-processor based system, the following acoustic equipment is required to accomplish the calibration:

1. An artificial ear consisting of a 6 $cm^3$ coupler meeting the requirements of ANSI S3.6-1969 (17) and terminated by a one-inch pressure microphone.
2. A microphone preamplifier.
3. A measuring or indicating amplifier.

6.2 Although the initial step of this procedure can be accomplished by one person, it is suggested that two persons be available, one inside the sound booth to monitor the measuring amplifier and one outside the booth to enter the required data at the micro-processor terminal.

Calibration - Step I

6.3 To start a calibration, one of the headset TDH-39 earphones is placed on the artificial ear, the microphone of which has been connected to the microphone amplifier, and the headset connected to the PPTD interface box. Only one of the earphones is calibrated on the artificial ear. It is assumed that the two earphones have been acoustically matched so that after the audiometer has been calibrated, both of the earphones will be within the level deviations permitted by ANSI S3.6-1969 (17). The calibration floppy disc is placed in the drive, and the following instruction is typed:

```
dL"calibrator RETURN
run RETURN
```

6.4 In response to the screen prompt, an "l" or "r" RETURN is typed, indicating which earphone (left or right) has been placed on the artificial ear. Although automatic earphone calibration takes place only between 250 and 8000 Hz (see paragraph 1.2), this calibration procedure begins at 125 Hz. Accordingly, the following display will appear on the screen:

**Processing 125 Hz - 105.5 dB - left ear** *

**enter calibrator delta (1 dec place)?**

6.5 If the SPL indicated on the measuring or indicating amplifier attached to the microphone preamplifier differs from the required ANSI level (shown on the screen), enter the difference (calibration delta) using a positive number to indicate that the indicated SPL is greater than the required ANSI level, and a negative number if it is less. Press RETURN and recheck the indicated SPL. If it is within 1 dB of the specified ANSI level, enter a "0" RETURN. Otherwise, enter the required 'calibration delta' as outlined above. After the "0" RETURN, the next frequency will appear on the screen with the specified ANSI SPL. The procedure will continue as described above until all the test-frequencies have been covered. The program will then generate a calibration table.

Calibration - Step II

6.5 The following procedure inserts the calibration table into the testing program. The earphones will be removed from the hearing-test and placed on the calibration couplers of the interface box (see Figures 3 and 4). The following commands are then typed:

```
dL"stest.bin RETURN
new RETURN
dL"p.w.g.bin RETURN
sys20000 RETURN
```

* The level 105.5 dB is the sound pressure level (SPL) specified in ANSI S3.6-1969 for 125 Hz when the calibration tone is set to 60 dB hearing level (HL). At the test frequencies of 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz, the specified levels are 95.5, 81.5, 77.0, 79.0, 80.0, 79.5, 85.5 and 83.0 dB SPL respectively for calibration-tone levels of 70 dB HL (18).

6.6 The system will display a series of messages on the screen. The last message (in reverse video) will be:

**Save program now!**

In response, type the following:

dsave"@p.w.g.bin" RETURN

6.7 The calibration procedure has now been completed. However, before removing the earphones from the calibration couplers on the interface box, a headset calibration should be conducted following the procedures outlined in paragraphs 1.1 and 1.2 to confirm that both earphones are within the limits specified by ANSI S3.6-1969. If the test fails, the earphone/frequency combination(s) that are out of limits may be determined by mounting each earphone in turn on the artificial ear and the SPLs generated at each test frequency noted as the audiometer is cycled through the MANUAL test mode at a 70-dB HL. The permitted deviation about the specified SPL are ±5 dB at 125, 6000 and 8000 Hz, ±4 dB at 4000 Hz, and ±3 dB at 250, 500, 1000, 2000 and 3000 Hz. Note that the automatic calibration will not fail at 125 Hz since this frequency is not included in the calibration (paragraph 1.2).

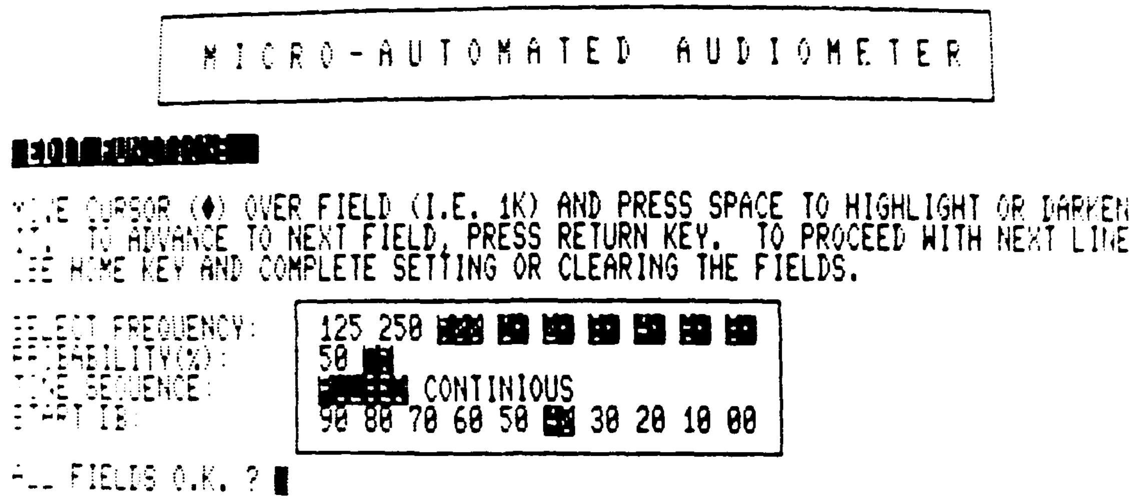



FIGURE C1. Microprocessor-controlled audiometer test-parameter menu.

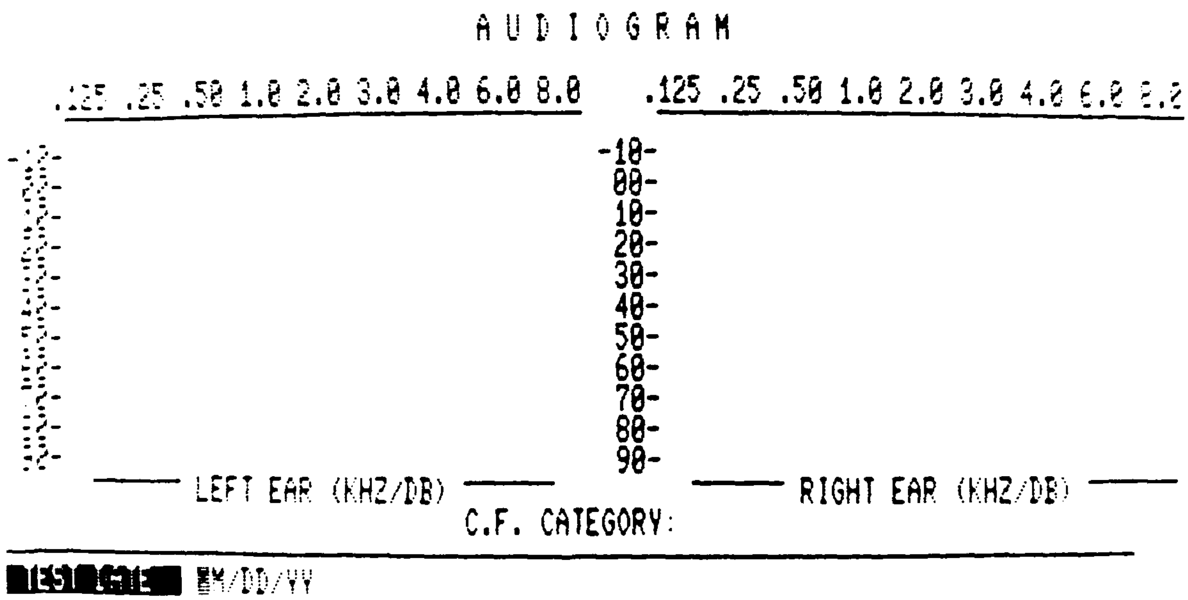



FIGURE C2. Display showing blank audiogram and test-date prompt.

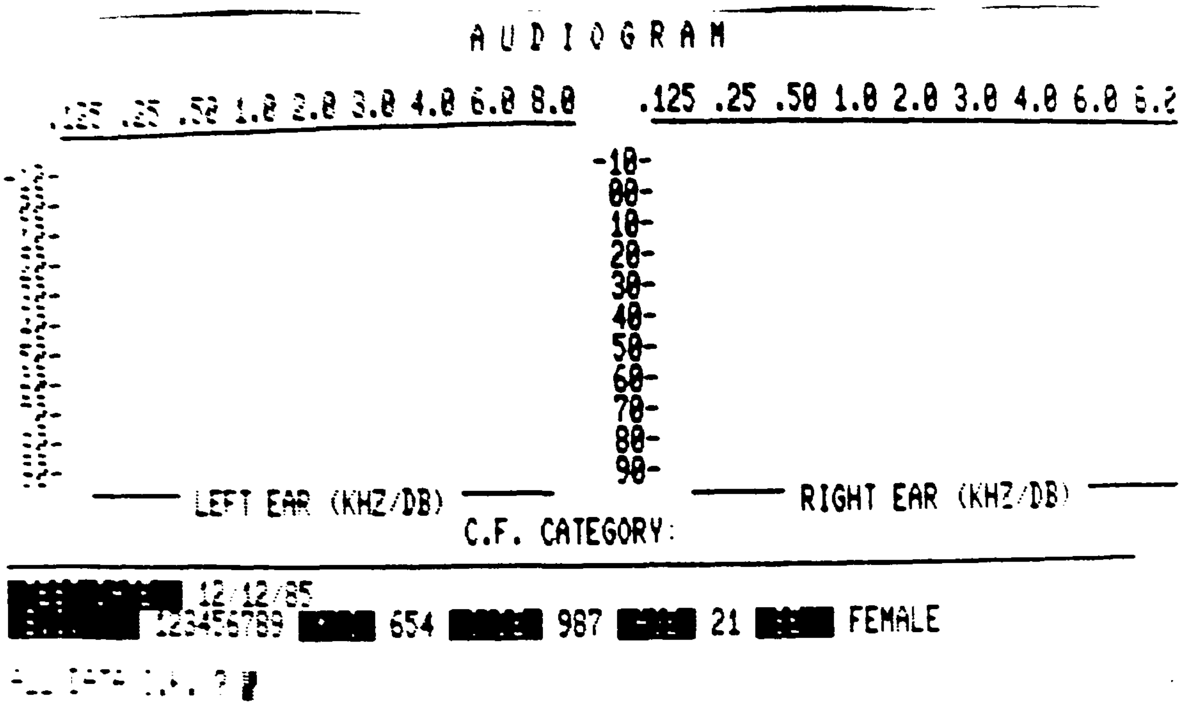



FIGURE C3. Display showing completed information-entry and prompt.

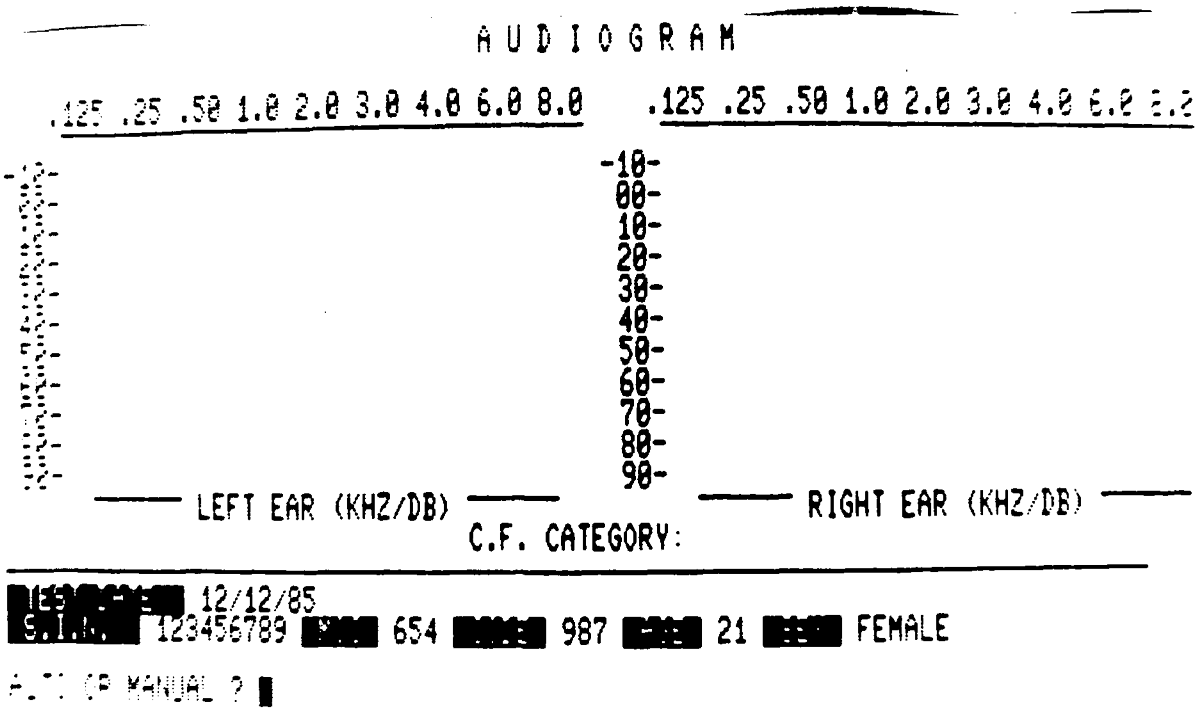



FIGURE C4. Display showing completed information-entry and AUTO OR MANUAL prompt.

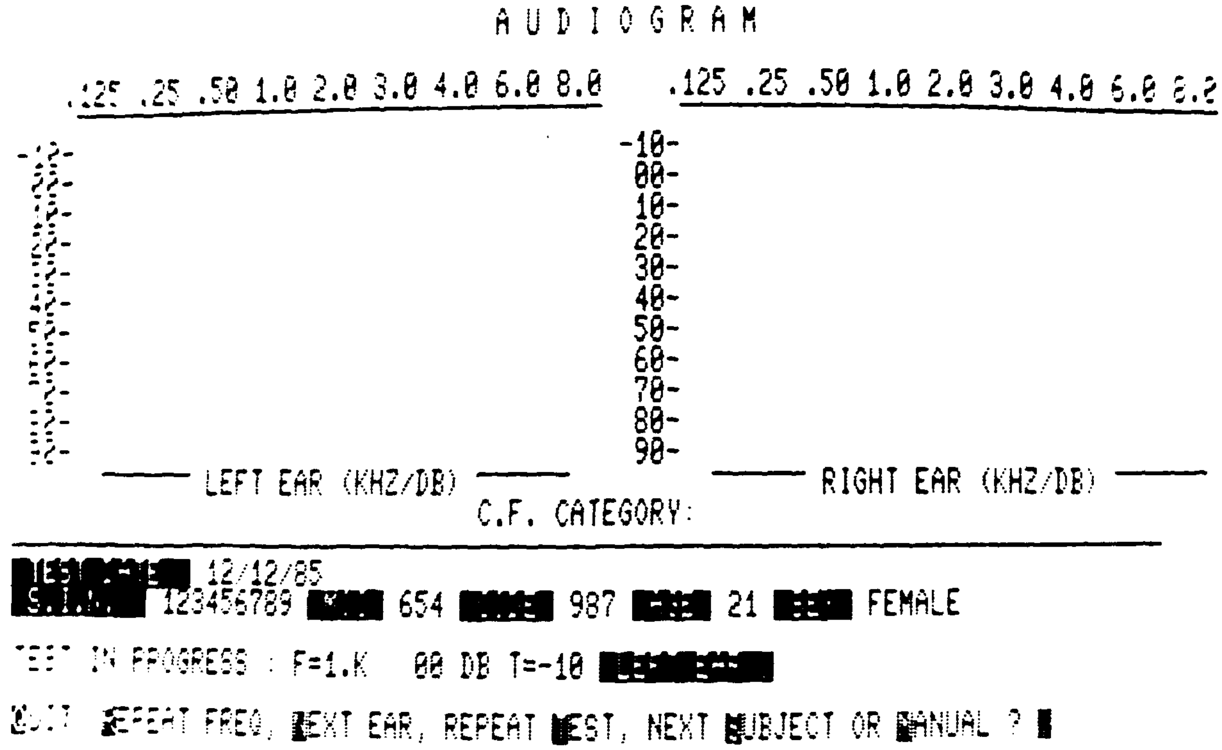



FIGURE C5. Display showing test-interrupt after 1000-Hz threshold has fallen beyond ±5 dB of the 1000-Hz reference test. As shown on the 'TEST IN PROGRESS' line, the test frequency = 1 kHz, the measured threshold = 0 dB, and the threshold T =-10 dB.

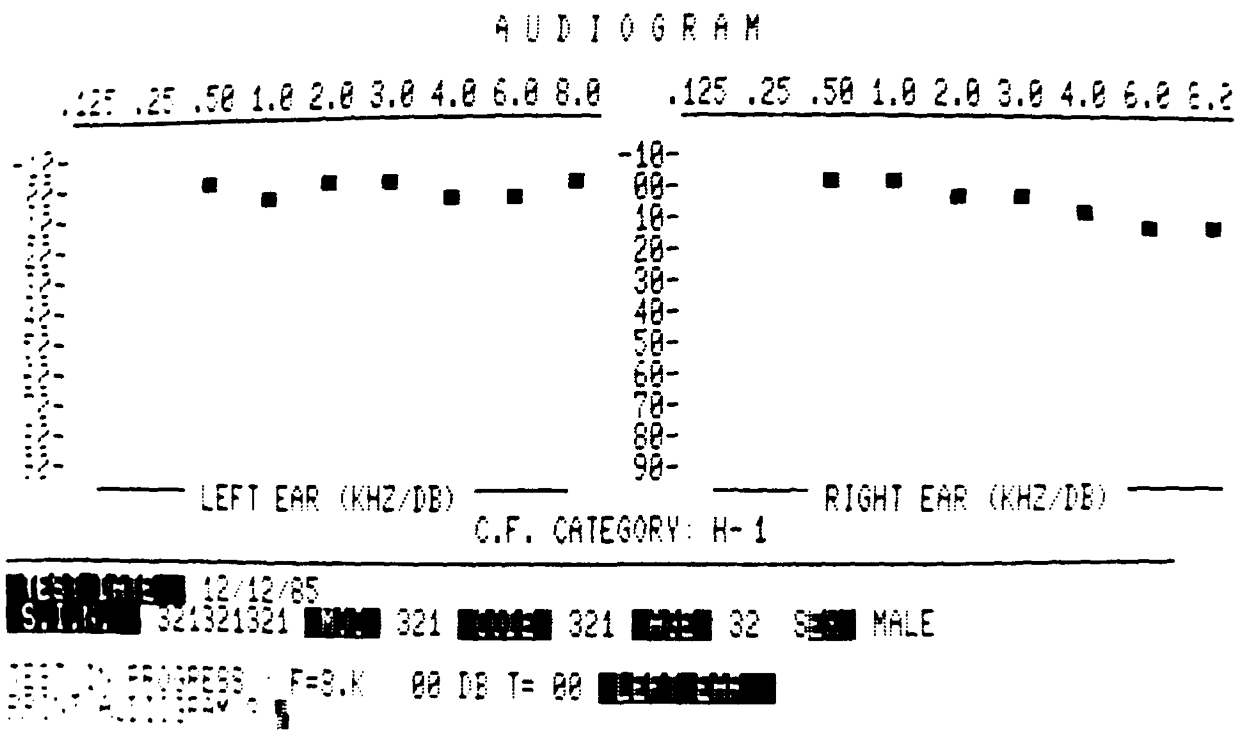



FIGURE C6. Display as it appears at the end of a hearing test.

```
                                    A U D I O G R A M

      .25 .50 1.0 2.0 3.0 4.0 6.0 8.0       .25 .50 1.0 2.0 3.0 4.0 6.0 8.0
     --------------------------------       --------------------------------
 -10 I                                  -10 I
     I                                      I
 000 I                                  000 I
     I                                      I
 010 I                                  010 I
     I                                      I
 020 I                                  020 I
   . I                                      I
 030 I                                  030 I
     I                                      I
 040 I                                  040 I
     I                                      I
 050 I                                  050 I
     I                                      I
 060 I        60A     60  60      60    060 I                60  60  60  60
     I    65C     65          65            I            65
 070 I                                  070 I        70
     I                                      I    75
 080 I                                  080 I
     I                                      I
 090 I                                  090 I

      ------ LEFT EAR (KHZ/DB) ------        ------ RIGHT EAR (KHZ/DB) -----
                                C.F. CATEGORY: HS
 -----------------------------------------------------------------------

       PATIENT'S NAME: OSCAR

            TEST DATE: 05/31/85

               S.I.N.: 443312152    AGE: 22    SEX: FEMALE
                  MOC: 123
                 CODE: 456

 THE APPEARANCE OF AN A, B OR C FOLLOWING
 A THRESHOLD INDICATES THE RESPONSE RANGE.

     A - 10 DB RESPONSE RANGE
     B - 15 DB RESPONSE RANGE
     C - 20 DB RESPONSE RANGE
 BLANK - 3X NO RESPONSE AT 90 DB

  NOTE - 125 AND 250 HZ ARE NOT TESTED IN THE AUTOMATIC
         MODE.  125 HZ WILL NEVER BE PRINTED AND 250 WILL
         REMAIN BLANK UNLESS TESTED MANUALLY.
```

FIGURE C7. Printout of hearing test results from terminal-screen display.

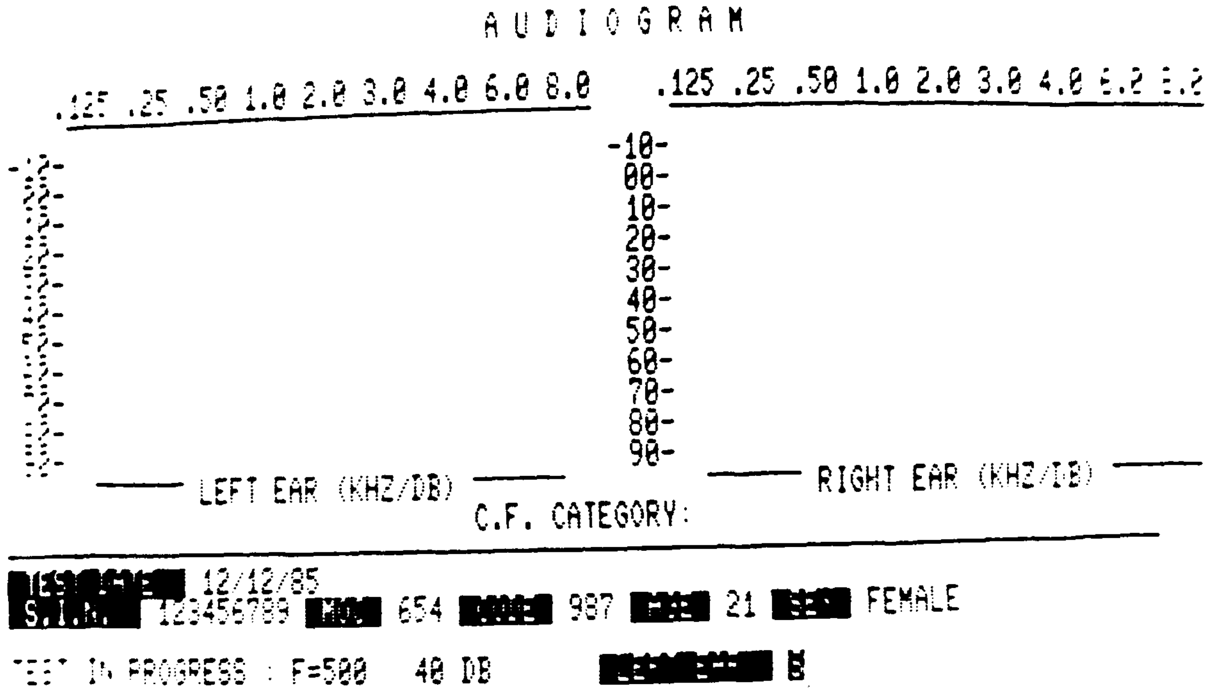



FIGURE C8. Display indicating that the test stimulus in ON, as shown by the highlighted 'S' to the right of the highlighted

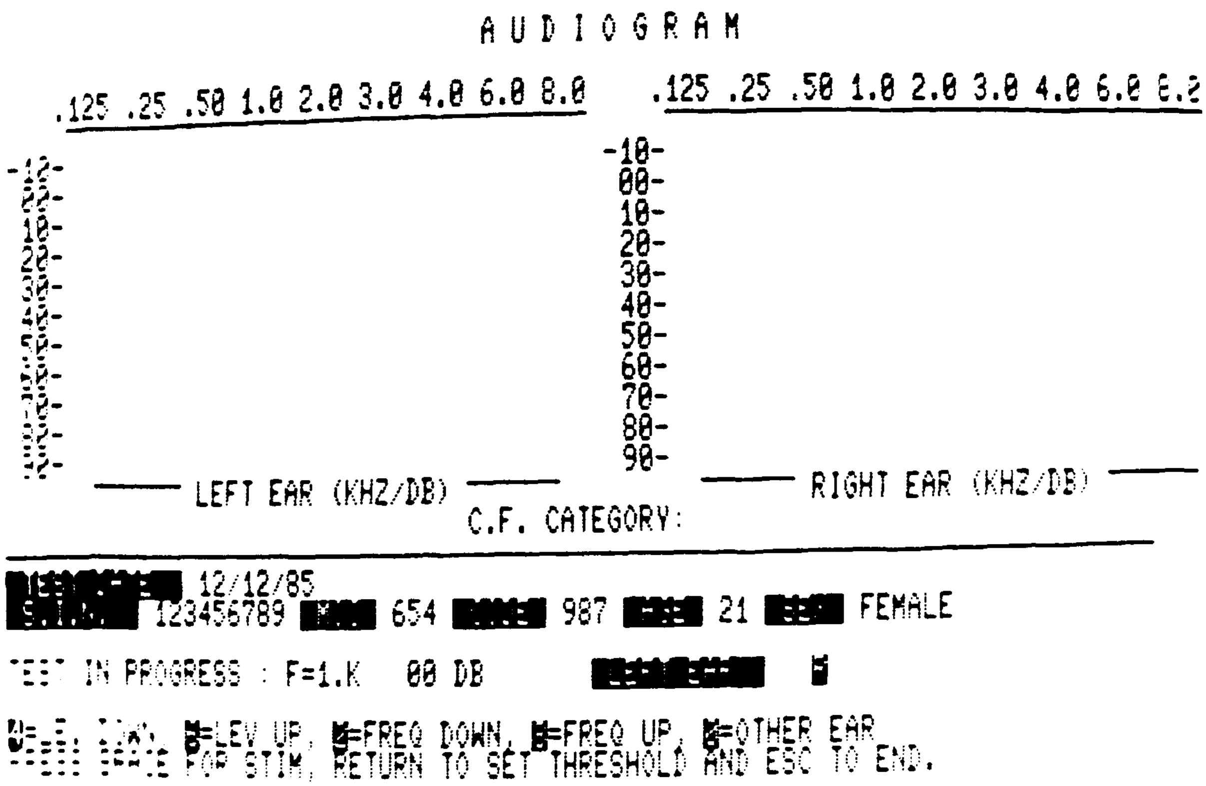



FIGURE C9. Display indicating a patient response, as shown by the highlighted 'R' to the right of the highlighted 'LEFT EAR' indicator.

# APPENDIX D

## MAXIMUM AMBIENT SOUND PRESSURE LEVELS FOR HEARING-TEST ROOMS

Maximum allowable SPLs in dB re 20 μPa for one-ear listening with no more than 1 dB threshold elevation above the reference hearing threshold levels[19].

| TEST-TONE FREQUENCY, Hz | OCTAVE-BAND SPL, dB | ONE-THIRD OCTAVE-BAND SPL, dB |
|---|---|---|
| 125 | 34.5 | 29.5 |
| 250 | 23.0 | 18.0 |
| 500 | 21.5 | 16.5 |
| 1000 | 29.5 | 24.5 |
| 2000 | 34.5 | 29.5 |
| 3000 | 39.0 | 34.0 |
| 4000 | 42.0 | 37.0 |
| 6000 | 41.0 | 36.0 |
| 8000 | 45.0 | 40.0 |

NOTE: If only screening audiometry at 10 dB HL is to be conducted, the permissible background SPLs for each test frequency may be increased by 10 dB.

# APPENDIX E

## EVALUATION OF THRESHOLD DETECTION CRITERIA ON REPEAT TEST VARIABILITY

This study was carried out to determine if threshold detection criteria affect repeat-test variability. Twenty-six subjects, 16 with normal hearing (HL not exceeding 30 dB at the test frequencies from 500 to 8000 Hz) and 10 with losses exceeding the normal-hearing criteria, were given hearing tests once each day over seven days. The subjects had little or no experience in near-threshold signal tracking, and were so selected to represent a typical cross section of the CF population. The subjects were instructed to press and release the hand-held response button each time the pulsed-tone was audible, and to do so immediately a tone was heard rather than after the tone presentation to ensure that they did not exceed the three-second response interval of the system. Thresholds were measured in 5-dB increments in accordance with the operation of the system.

The first days' tests were used to familiarize the subjects with the threshold-detection procedure. Hence, these data were not used in the subsequent analysis. The remaining six tests were alternated between the 50 and 75 per cent detection criteria and were counter balanced across subjects. In addition, the time taken to complete each test was recorded.

In order to assess the differences in thresholds due to detection criteria, a repeated measures analysis of variance by frequency was used on the data. It is noted that an HL value of -10 or +90 dB may not represent a true threshold since these are the limits on the sound-intensity continuum at which threshold searching is terminated. As a result, it was decided to exclude from the analysis any set of data (six thresholds (three replications at each detection criteria) for a given ear (left or right) and frequency) containing either of the limiting values. The resulting pooled within-subject-replication standard deviations are given in Table E-I, and are not significantly different ($p<.01$) from those reported by Harris in his study of microprocessor audiometry [20].

TABLE E-I

WITHIN-SUBJECT REPLICATION STANDARD DEVIATIONS FOR HEARING TESTS USING 50 AND 75 PER CENT THRESHOLD DETECTION CRITERIA

| | Threshold Detection Criterion | |
|---|---|---|
| Test Frequency (Hz) | 50 Per Cent | 75 Per Cent |
| 500 | 3.19 dB | 3.79 dB |
| 1000 | 3.32 dB | 3.67 dB |
| 2000 | 3.68 dB | 5.73 dB |
| 3000 | 4.23 dB | 4.12 dB |
| 4000 | 4.35 dB | 6.38 dB |
| 6000 | 7.10 dB | 7.62 dB |
| 8000 | 7.24 dB | 6.46 dB |

The mean and standard deviation of the difference in each subject's mean HL at the 50 per cent detection criteria $\bar{x}_{HL50}$ and at the 75 per cent criteria $\bar{x}_{HL75}$ (each averaged over three trials) is shown in Table E-II as a function of frequency. Although the differences in $\bar{x}_{HL50}$ and $\bar{x}_{HL75}$ are small, the standard deviations at 4000, 6000 and 8000 Hz are relatively large. It is at these frequencies that the wavelength of sound approaches the length of the ear canal. As a result, small changes in the day-to-day position of the earphone on the ear become an significant source of experimental error. Whereas 82.1, 63.3 and 83.3 per cent of the values of $\bar{x}_{HL50}$ - $\bar{x}_{HL75}$ are 5 dB or less at 4000, 6000 and 8000 Hz respectively, at the four test frequencies from 500 to 3000 Hz, the corresponding percentages are 97.0, 100., 93.3 and 96.3 dB respectively [21].

In analyzing the time-measurement data, subjects were categorized as follows: normal-hearing and hearing-loss subjects who completed the three tests at each detection-criterion condition without a program interrupt (due to inconsistent responses), and normal-hearing and hearing-loss subjects whose tests were interrupted during testing. It was decided to not include the results of subjects whose tests were

interrupted two out of three of the trials in each criterion-condition, since their continued *inconsistent responses* might preclude any meaningful analysis. The overall averages and standard deviations for each of the four subject groups are shown in Table E-III as a function of the 50 and 75 per cent threshold detection criteria.

TABLE E-II

DIFFERENCES IN WITHIN-SUBJECT MEAN HEARING LEVELS, AND STANDARD DEVIATIONS, FOR THREE TESTS USING 50 AND 75 PER CENT THRESHOLD DETECTION CRITERIA

| | | Difference Between Subjects' Mean HL Using 50 and 75 Per Cent Detection Criteria | |
|---|---|---|---|
| Test Frequency (Hz) | Sample Size | Mean Difference | Standard Deviation |
| 500 | 33 | -1.3 dB | 2.82 dB |
| 1000 | 32 | +0.2 dB | 2.41 dB |
| 2000 | 30 | -0.1 dB | 3.43 dB |
| 3000 | 27 | -0.3 dB | 2.89 dB |
| 4000 | 28 | -0.1 dB | 4.67 dB |
| 6000 | 30 | +0.2 dB | 7.69 dB |
| 8000 | 36 | +0.2 dB | 4.46 dB |

TABLE E-III

MEAN TIMES (AND STANDARD DEVIATIONS) TAKEN TO COMPLETE HEARING TESTS

| | Threshold Detection Criteria | | | | | |
|---|---|---|---|---|---|---|
| | 50 Per Cent | | | 75 Per Cent | | |
| | n | $\bar{x}$ | σ | n | $\bar{x}$ | σ |
| Non-Interrupted Tests: | | | | | | |
| Normal-Hearing Subjects | 11 | 6:34 | 3:43 | 10 | 7:05 | 4:15 |
| Hearing-Loss Subjects | 9 | 11:31 | 1:14 | 7 | 15:14 | 1:27 |
| Interrupted Tests: | | | | | | |
| Normal-Hearing Subjects | 45 | 8:53 | 2:52 | 45 | 10:22 | 4:21 |
| Hearing-Loss Subjects | 33 | 11:22 | 1:02 | 33 | 12:20 | 4:59 |

NOTES:
1. *Interrupted tests* are automatic-mode tests interrupted by inconsistent responses and requiring the technician to have the test repeated at the interrupted frequency (see Appendix C, paragraphs 2.1 and 2.2).
2. Normal-hearing is defined herein as hearing thresholds not exceeding 30 dB at the test frequencies between 500 and 8000 Hz.

Across the four subject groups, the time needed to complete the 75 per cent detection-criterion tests was longer by 0:31 to 3:43 minutes. Of these, only the difference for the non-interrupted/hearing-loss condition was significant ($p<.01$). Interestingly, the number of interrupted tests were the same among both the normal- and hearing-loss subjects, although the time variations were greater with the 75 per cent criteria trials [21].

The subjects employed in this study were intended to represent a typical cross section of the population, ***generally naive in psychophysical testing***, that would be encountered among CF personnel. That is, the subjects had little of no experienced in near-threshold signal tracking and detection, and were not accustomed to attending continuously to such a task for periods often in excess of six to eight minutes. The relatively large number of inconsistent responses observed in the study may, therefore, be representative of what could be expected in Base Hospital MIRs where periodic screening audiometry will be conducted.

It would appear, then, that the use of too rigorous a threshold detection criterion, with the accompanying increase in testing time, is inappropriate. It was not demonstrated in this study that threshold criteria affect replication variances [21]. Accordingly, a 50 per cent threshold detection criterion should be used in routine microprocessor-controlled periodic audiometry in the CF.

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ABSTRACT

This report describes a prototype microcomputer-based audiometer designed to demonstrate the potential of such technology for routine periodic hearing testing in the Canadian Forces (CF). Besides the microcomputer and its dual-disk drive, display screen and printer, the system is comprised of an interface box containing a crystal clock, frequency synthesizer, digital attenuator, electronic switch, audio amplifier, acoustic earphone calibrators, and patient-response interface circuitry. The threshold-detection paradigms are based on the modified Hughson and Westlake procedure. The associated software provides prompts to the technician for parameters and data for each patient (e.g., age, social insurance number (SIN), military occupation code (MOC), along with prompts during the testing if problems are encountered. After a test is completed, the patient's CF hearing category is computed and displayed on the screen audiogram form, and the test results are stored automatically in a disk file for future reference.


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Audiometer

Hearing Testing
Computer Audiometry